# Cold Climate Sewage Lagoons

Proceedings of the June 1985 Workshop, Winnipeg, Manitoba

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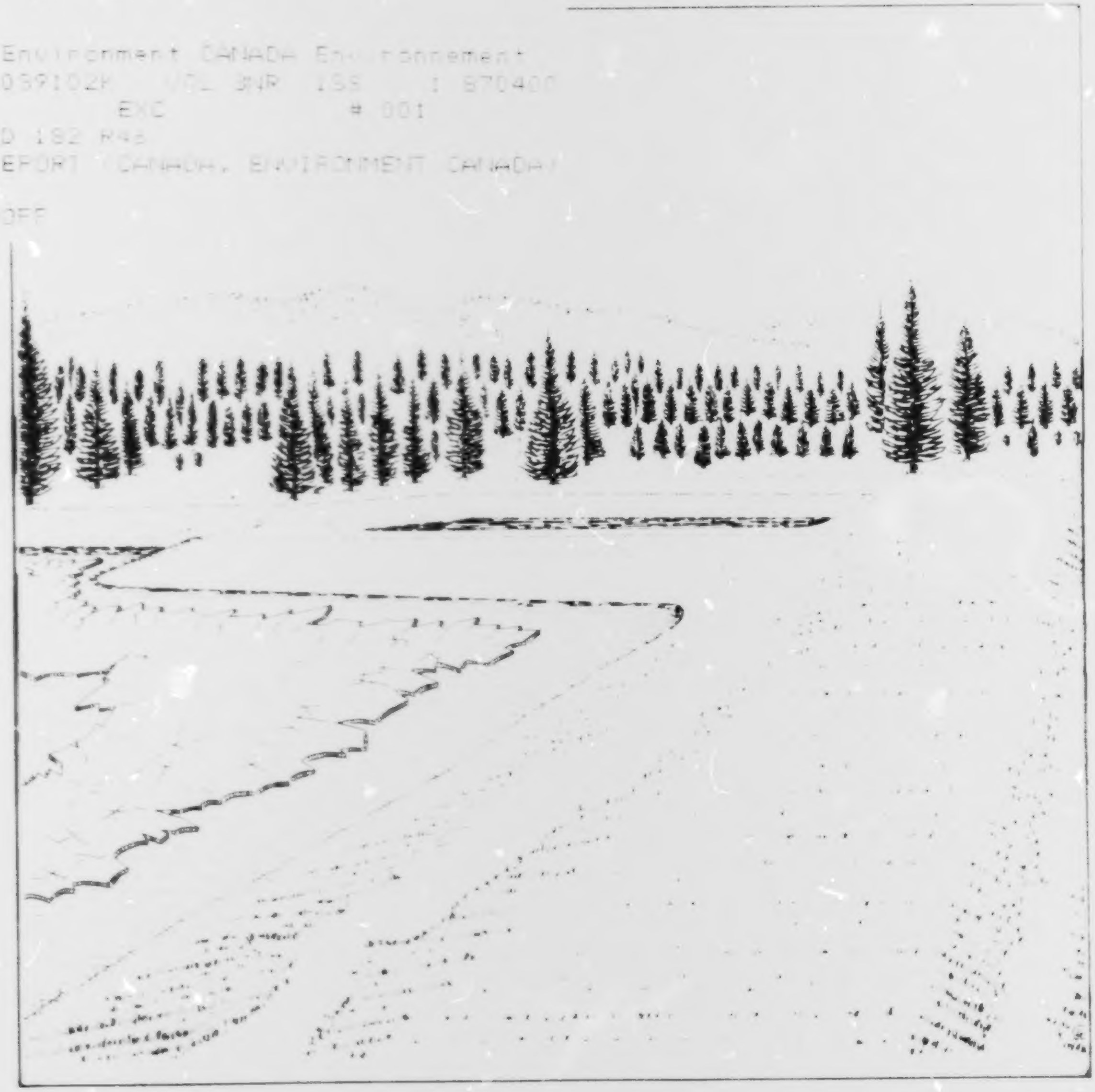

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# COLD CLIMATE SEWAGE LAGOONS

## Proceedings of the 1985 Workshop, Winnipeg, Manitoba

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Sponsors:

Technology Development and Technical Services Branch, Environment Canada
Technical Services and Contracts Branch, Indian and Northern Affairs Canada
Medical Services Branch, Health and Welfare Canada

Report EPS 3/NR/1
April 1987

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## NOTICE

The proceedings were prepared primarily from the transcripts of the workshop. Some points were clarified or expanded with information from submitted papers. The opinions and facts expressed at the workshop are stated here as accurately as possible, a feat in which the editors called on the assistance of the following reviewers of the draft:

| | |
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Dan Smith gave the introductory presentation which he based on the report to Environment Canada, "Critical Evaluation of the Operation and Performance of Lagoons in Cold Climates". He and Gordon R. Finch are its authors.

Sherwood Reed made Dr. Tim Tilworth's report available to participants of the workshop. This is merely one example of his support and encouragement.

John A. Cormie sent construction drawings of typical lagoon systems in the Yukon Territory.

## TABLE OF CONTENTS

Page

1 OVERVIEW OF WORKSHOP 1

1.1 Sewage Lagoons: The Most Commonly Used Wastewater Treatment Process in Canada 1
1.2 Quest for More Knowledge 1
1.3 Objectives 3
1.4 Participants 3
1.5 Organization 4
1.5.1 The Themes of this Workshop 4
1.5.2 Scope of this Workshop 4
1.6 Identified Research Needs 5
1.7 Workshop Evaluation 5
1.8 Getting on With a Research Plan 6

2 THE WORKSHOP 6

2.1 Needs Expressed by Various Professionals 8
2.1.1 Pollution Control Officers 8
2.1.2 Public Health Officers 8
2.1.3 System Owners 8

Small lagoons 10
Large lagoons 10

2.1.4 Consultants 10
2.1.5 University Professors 11
2.2 Sessions on Lagoon Theory and Practice 12
2.2.1 Lagoon Theory 12
2.2.2 Lagoon Design and Operation 12

Site selection 15
Process design 15
Size of population as a limit 15

2.2.3 Upgrading Lagoon Systems 16

Practices in Ontario 16
Aquaculture 16
Wetlands treatment 16

2.2.4 Aerated Lagoons 17

Completely mixed aerobic aerated lagoons 17
Incompletely mixed facultative aerated lagoons 18

2.2.5 Aerobic/Facultative Lagoon Models 18

Page

2.3 Getting On With It: Elements of a National Cold-Climate Lagoons Research Plan 19
2.3.1 Objective of Future Research 19
2.3.2 Identifying the Research Needs 19
2.3.3 Discussions Arising From Identification of Potential Topics in Research Projects 20

Developing monitoring standards (Projects, 44, 45, 54 and 61) 21
Odour control and prevention (Project 33) 22
Evaluation of indicator organisms as representative of the presence of pathogens (Project 46) 22
Definition of the biokinetics in a lagoon under ice cover (Project 1) 23
Design criteria for small lagoons (Project 49) 23
Design criteria to optimize pathogen removal (Project 56) 24
Use of wetlands or other aquatic components to upgrade lagoon performance (Project 39) 24
Dynamic model of lagoon process (Project 47) 25

2.3.4 Summary 26
2.4 Identified Post-Workshop Activities 27
2.4.1 Organization 27
2.4.2 Objectives of Entire Organization 27
2.4.3 Strategy 28
2.4.4 Priorities 28
2.4.5 Activities 28
2.4.6 Suggested Responsibilities for Delegation by Steering Committee 29
2.4.7 Making a Commitment 29
2.5 Closing Statements 29

Government regulators 29
Consultants 30
University professors 30

2.6 Workshop Evaluation 31

3 LAGOON THEORY AND DESIGN 32

3.1 State of the Art 32
3.1.1 Lagoon Treatment Performance in Alberta 32

Study into continuous overflow 33
Study to measure successive stages over the 2-week discharge period 34

3.1.2 State of the Art vs. Design Criteria of Regulatory Agencies 34
3.1.3 Wastewater Characteristics 38
3.1.4 Sludge Buildup 40
3.2 The Environment and Public Health 40

Page

3.2.1 Impact of Lagoons on the Environment 41
3.2.2 Public Health Concerns 42

Bacteria/viruses: the main concern in the Territories 42
R-factor 42
Mussels 43
Aerosols 43

3.2.3 Honey Bags as Means of Waste Disposal 44
3.2.4 Validity of Standard Test Methods as Related to Suspended Solids in Sewage Lagoon Systems 44

Testing for total dissolved solids rather than BOD 45
Validity of fecal coliforms as indicator organisms 45
Effluent toxicity testing 45

3.3 Operations and Process Control 46
3.3.1 Lagoon Performance and its Monitoring 46
3.3.2 Record-keeping 47
3.3.3 Maintenance 48
3.3.4 Operator Training 49
3.4 Upgrading the Performance of Existing Lagoons 51
3.4.1 Overview of Ontario Experience 51

Nutrient removal 51
Reduction in oxygen demand and bacteria 52
Toxicity reduction 53
Hydrogen sulphide odour control 54

3.4.2 Natural Wetlands Treatment 54

Saskatchewan 55
Northwest Territories 55
Ontario 55
Northern Quebec 56
Summary 56

3.4.3 Nutrient Removal by Duckweed 56
3.4.4 Harvesting Biological Production 57
3.5 Lagoon Theory 59
3.5.1 Lagoon Limnology 59
3.5.2 Organisms in Wastewater 61
3.5.3 Natural Disinfection Mechanisms 62
3.5.4 Effects of Temperature 63
3.5.5 Effects of Ice Cover 63

On freezing 64
During mid-winter 64
At spring breakup 64

Page

3.5.6 Bottom Sediments 65
3.5.7 Nitrogen Compounds 65

- Nitrification-denitrification 65
- Volatilization of ammonia 66

3.5.8 Alkalinity Changes 66
3.5.9 Dissolved Oxygen (DO) Levels 66
3.5.10 Psychrotrophic Bacteria 67

- Studies conducted at Inuvik, N.W.T. 67
- Lagoon sludge characteristics 72
- Conclusions 75

3.5.11 Lagoon Configuration 75
3.5.12 Facultative Lagoon Models 76
3.6 Lagoon Design 78
3.6.1 Site Selection 78

- Isolation distances 79
- Litigation of odour complaints 80

3.6.2 Construction in Permafrost Regions 81

- Finding a suitable site 81
- Avoiding thawing problems 82

3.6.3 Facultative Lagoons 83

- Primary anaerobic cells 86
- Pre-aeration cells 87
- Main treatment cells 87
- Polishing/storage cells 88

3.6.4 Aerated Lagoons 89

- Loadings and effluent quality 89
- Aeration devices 90
- Short-circuiting 92
- Dissolved oxygen under ice cover 92
- Mathematical model coefficients 92
- Phosphorus removal 95

3.6.5 Operational and Research Considerations 97

- Effluent control structures 97
- Erosion protection 97
- Seepage prevention 98

Page

APPENDIX A WORKSHOP PROGRAM 99

APPENDIX B PARTICIPANTS 105

APPENDIX C SUMMARY OF IDENTIFIED RESEARCH NEEDS ORGANIZED BY TOPIC AREA AND PRIORITY 113

APPENDIX D CONTRIBUTIONS BY PRESENTERS AND DISCUSSORS 121

- D-1 Lagoons in the City of Winnipeg 123
- D-2 Lagoon Treatment Performance in Alberta 125
- D-3 Summary of Design Models for Sewage Lagoons 132
- D-4 Sewage Lagoon Design Criteria 137
- D-5 Operator Training Concept 144

APPENDIX E DOCUMENTS ABOUT COLD-CLIMATE LAGOONS 149

APPENDIX F WORKSHOP EVALUATION 157

## LIST OF TABLES

| Table | | Page |
|---|---|---|
| 1 | SUMMARY OF IDENTIFIED RESEARCH NEEDS: 10 PROJECTS OF GREATEST INTEREST | 7 |
| 2 | RAW WASTEWATER CHARACTERISTICS | 39 |
| 3 | DATA FROM UPGRADED ONTARIO LAGOON SYSTEMS | 54 |
| 4 | PHYSICAL AND CHEMICAL PARAMETERS AT SAMPLING STATIONS IN INUVIK SEWAGE LAGOON SYSTEM | 70 |
| 5 | AVERAGE SOLIDS CONCENTRATION OF CELL CONTENTS | 71 |
| 6 | AVERAGE BOD AND COD VALUES | 71 |
| 7 | BACTERIAL COUNTS BY TYPE | 72 |
| 8 | CHARACTERISTICS OF THE ACCUMULATED SLUDGES FROM THE INUVIK SEWAGE LAGOON SYSTEM | 73 |
| 9 | INTERPRETATION OF RESULTS FROM MATHEMATICAL MODELLING | 94 |

# 1 OVERVIEW OF WORKSHOP

## 1.1 Sewage Lagoons: The Most Commonly Used Wastewater Treatment Process in Canada

There are about 1000 sewage lagoons in Canada. That represents approximately half the wastewater treatment systems reported in Canada. Alberta, Manitoba, Saskatchewan, the Northwest Territories and the Yukon Territory rely heavily (70% or more) on this form of treatment.

Lagoons have been so widely used because they have been effective in treating the wastewater from small communities at low cost. A lagoon can be built on inexpensive land near a community, requires little energy and maintenance, and the maintenance it does require need not be performed by skilled operators. Although, in the past, effective treatment of wastewater has meant that the removal of biochemical oxygen demand (BOD) and suspended solids, by views currently held that may not be satisfactory to constitute effective wastewater treatment.

Wastewater treatment aims to preserve public health and minimize the environmental impact of effluents. Lagoons perform this function with varying success. During periods of relatively warm weather and adequate sunlight, the treatment performance in terms of BOD and fecal coliform (FC) reduction is good. In periods of cold weather and limited sunlight, the treatment performance is poor. A number of design and operational modifications have been developed to overcome some limitations of the process. But the variability of treatment performance remains cause for considerable concern among designers, operators, and staff of regulatory agencies.

More R&D must be undertaken if designers and operators are to gain the knowledge and understanding necessary for the effective control of the environmental and biotechnical factors influencing cold-climate lagoon systems. (Cold-climate lagoon systems are the critical systems; they require increased storage and treatment times).

With more knowledge, the relations between economics and public health and environment can be better understood, and lagoons can then be more precisely designed to achieve the desired performance.

## 1.2 Quest for More Knowledge

In August and November of 1982, the Environmental Protection Service (EPS) corresponded with an ad hoc group of environmental engineers from federal, provincial, territorial governments and universities in Canada concerning the prospect of forming a working group for the preparation of a comprehensive manual on sewage lagoons designed for and operating under Canadian conditions.

The response was so positive, particularly from the Department of Local Government, Government of the Northwest Territories, that in December 1982 the then Technology Development Branch contracted Daniel W. Smith, Professor, Department of Civil Engineering, University of Alberta, for a critical literature review to establish a base of information on the past performance, process theory design, construction and operation of cold-climate lagoons. ("A Critical Evaluation of Lagoons in Cold Climates," October 1983.)

In March 1983, Professors Smith, Heinke, and Labonte jointly announced the initiation of a Lagoon Research Program to be organized as a co-ordinated effort among the Universities of Alberta and Toronto, and École Polytechnique to initiate project efforts using support funds from the Natural Science and Engineering Research Council (NSERC). A number of projects, transcending federal and provincial government interests, were identified. A planning meeting hosted by the University of Toronto in March 1983 was attended by government representatives including the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).

In August 1983, the draft of EPA-625/1-83-015, "Design Manual for Municipal Wastewater Stabilization Ponds" was reviewed by Sherwood C. Reed, CRREL, who assisted EPA in its preparation. (The publication was subsequently released in October 1983). It identified 29 information needs to improve the state-of-the-art on cold-climate sewage lagoons. The publication represents Sherwood Reed's contribution to this initiative to develop a co-ordinated international research effort on cold-climate lagoons. Further, CRREL contracted Professor Timothy Tilsworth to report on the status of cold-climate lagoons in Alaska (E 84-11 "Cold Climate Lagoon Status", May 1984).

In November 1983, the three universities in cooperation with CRREL solicited the support of government agencies from across Canada for its proposed 5-year "Research Program for Lagoon Systems in Cold Climates" based on the identified research needs arising from the cited EPA- and EPS-sponsored contracts. The research needs were classified into six areas with a total of 42 preliminary project ideas.

In the fall of 1984 the Environmental Protection Service (Environment Canada) in collaboration with the Technical Services & Contracts Branch (Indian and Northern Affairs Canada) and the Medical Services Branch (Health and Welfare Canada) began planning for a national workshop on cold-climate lagoons to bring together a selected group of workers experienced in all aspects of cold-climate lagoon systems to reach a consensus on the elements of a co-ordinated research/study plan. The workshop would lead to the formation of a steering committee with working groups on a joint government, university, and industry basis to implement the required studies and eventually prepare the desired manuals on the design, construction, and operation of lagoons in cold climates.

A new report by Environment Canada (EPS 4/NR/1, "Sewage Lagoons in Cold Climates") was prepared as the background reference for the workshop. The report is based on the October 1983 literature review prepared at the University of Alberta.

This comprehensive, co-ordinated approach, involving all sectors concerned with cold-climate lagoons, was undertaken on recognizing that no one group alone had the resources to meet the challenge.

## 1.3 Objectives:

1) To identify those areas that require research so that more definitive information for the preparation of recommendations for lagoon design and operation in cold-climate conditions can be advanced;
2) To agree on methods of disseminating information to those planning, designing, and operating lagoons as a form of pollution abatement; and
3) To mount an R&D program that responds to the need for more information such as:
    - examining our understanding of sewage lagoons that are subjected to seasonal ice cover, and
    - considering more rational and precise design and operating criteria for sewage lagoons in cold climates where increased treatment and storage times are required.

---

Anticipated Results: A master study plan of literature reviews, laboratory research, and field investigations to be supported and managed by a consortium of sponsors by priority.

---

## 1.4 Participants

About 50 government regulators, researchers, consultants, and owners were invited to be participants at this workshop to share their expertise about cold-climate sewage lagoons. Participants were expected to contribute to the success of the workshop by acting as chairman, theme speakers, lead discussors, and working group leaders/recorders.

Each participant was asked to take to the workshop a one-page summary of the information he planned to introduce during the discussion periods. These summaries were meant for inclusion in the Proceedings.

## 1.5 Organization

The workshop lasted for 2-1/2 days. Six themes concerning lagoons were addressed, generally one theme in the morning session, another theme in the afternoon session. In the afternoon of the second day two themes were addressed.

Throughout the workshop, topical reports and lists of relevant publications were on display. See Appendix E for details.

**1.5.1 The Themes of this Workshop.** Dr. Dan Smith, Professor of Civil Engineering at the University of Alberta, presented the opening address in which he gave an overview of the report "A Critical Evaluation of the Operation and Performance of Lagoons in Cold Climates".

1. Where are we with lagoons?

   Under this theme we took a brief inventory of concerns people have in dealing with lagoons.

2. Lagoon Theory.

   Under this theme, climatic, biological, physio-chemical, and geotechnical considerations were covered, as well as the influences lagoon cell configuration, etc. have on the efficiency of the processes occurring in the cells.

3. Lagoon Design and Operation.

   Addressed here were:

   site selection,
   design models,
   process design,
   construction, and
   operation.

4. Upgrading Lagoon Systems.

   This theme dealt with innovative methods of achieving high-quality effluents either by modifications to lagoon technology or by the introduction of new ideas such as aquaculture.

5. Where do we go from here?

   This summarized information gaps identified during the first 2 days of the workshop. In keeping with its objective, the information gaps are to form the plan for future commitments to research.

6. Getting on with it.

   Under this theme we were, by consensus, formulating research priorities and developing the necessary organizational framework for their expeditions implementing.

The workshop was organized to promote an unfettered exchange of ideas that speakers may have provoked.

1.5.2 **Scope of this Workshop.** The focus of concern at this workshop was primarily on conventional facultative lagoons and anaerobic lagoons for therein lies most of the experience with lagoon systems in Canada. The workshop, however, also included some insights into aerated lagoons. The need to discuss aerated lagoons more extensively than planned came to light only on realizing that in Quebec those are the type of lagoons mostly used. Initially aeration devices were to be considered only as a means of upgrading conventional lagoons for odour control and increased BOD loading.

Treatment of industrial wastes in lagoons, whether conventional or aerated, was outside the scope of this workshop.

### 1.6 Identified Research Needs

Lagoons are expected to treat more pollutants than ever before. For them to maintain their position as the least-cost method of wastewater treatment for small communities, more knowledge of the significance of the physical configuration and number of cells and a better understanding of the limnological aspects is required for the design and operation of better lagoons and for more reliable lagoon performance. The workshop built upon the 42 previously identified project topics (see Section 1.2) and increased that number to 65 as listed in Appendix C.

Once the list was completed, each participate ranked the projects on a 1-to-10 scale (see Section 1.2) of importance. The 10 projects of greatest importance and interest to the participants are listed in Table 1. The top 5 are:

- a survey to better document existing lagoon problems and innovative solutions;

- a task force to develop nationally acceptable lagoon monitoring standards;
- a study to collect and interpret the performance and effluent quality of cold-climate lagoons on a seasonal basis;
- a team to address odour prevention and control; and
- an evaluation of suitable indicator organisms as representative of the presence of pathogens in cold-climate lagoon systems.

The concensus reached during the workshop has been made available in these proceedings as an encouragement for the participants themselves and other concerned persons to focus on these needs for the enhancement of cold-climate lagoon systems.

## 1.7 Workshop Evaluation

The participants found that this workshop provided:

- professional incentive and moral support;
- a good exchange of recent research findings and new ideas;
- the opportunity to contribute to the determination of future research thrusts;
- readier access to information;
- the opportunity to meet professional colleagues; and
- insights into a common problem from different points of view.

Because of the benefits derived from this workshop participants recommended future workshops at regular intervals, when new information becomes available, possibly every 2 years.

The contributions by Al Townshend and Dan Smith to the organization and conduct of the workshop were recognized. Through the excellent dialogue and free thinking encouraged, this workshop has met its objectives and expectations.

## 1.8 Getting on With a Research Plan

During the workshop, participants made various suggestions about mechanisms and activities to be undertaken by all concerned with implementing a National Cold-Climate Lagoons Research Plan in Canada (see Table 1).

Responsibility for the Plan would be vested in a steering committee with working groups to carry out specific assignments. The objectives would be to:

- identify solutions,
- transfer information, and
- introduce new approaches to lagoon design, construction, and operation for improving the performance and reliability of lagoon systems.

TABLE 1 SUMMARY OF IDENTIFIED RESEARCH NEEDS: THE 10 PROJECTS OF GREATEST INTEREST (Cold climate sewage lagoons Workshop; Fort Garry Hotel, Winnipeg, Man., June 5-7 1985)

| | Topic Area | Project Number | Project Description | Ranking |
|---|---|---|---|---|
| 1.0 | State-of-the-Art | 27 | Survey of existing operational lagoons to document problems and innovations. | 1st |
| 3.0 | Operation and Process Control | 44 | Develop monitoring standards. | 2nd |
| 1.0 | State-of-the-Art | 26 | Performance and effluent quality from seasonal discharges. | 3rd |
| 2.0 | Environmental/ Health Concerns | 33 | Odour control and prevention. | 3rd |
| 2.0 | Environmental/ Health Concerns | 46 | Evaluation of indicator organisms as representative of the presence of pathogens. | 3rd |
| 5.0 | Theory/Design | 1 | Define the biokinetics in a lagoon under ice cover. | 4th |
| 5.0 | Theory/Design | 49 | Design criteria for small and temporary lagoons. | 4th |
| 5.0 | Theory/Design | 56 | Design criteria to optimize pathogen removal. | 4th |
| 4.0 | Upgrading Technologies | 39 | Use of wetlands or other aquatic components as part of the overall lagoon treatment system. | 5th |
| 3.0 | Operation and Process Control | 45 | Develop operating standards. | 5th |

The Plan would focus on in-depth studies of a number of selected lagoon systems to gather new data rather than relying on the analysis of existing data which may not prove reliable enough.

Activities under the Plan would be monitored and evaluated. The mechanism would allow for priority changes as new needs arise and as solutions to old ones are found. This would be done through project review meetings and subsequent national workshops.

# 2 THE WORKSHOP

## 2.1 Needs Expressed by Various Professionals

**2.1.1 Pollution Control Officers.** From every wastewater treatment system we expect an effluent quality that protects the receiving waters. Generally, lagoons seem to have met this expectation well enough for smaller communities where only reductions in BOD and suspended solids were required. But that is not all that is required nowadays.

Advancement in the understanding of wastewater and its treatment has not changed this expectation, but rather given us a more microcosmic perspective. We know now of more substances to be controlled, but do we know how to control them in lagoon systems?

A lagoon relies for its effectiveness on biochemical interactions. But how effective can a lagoon be in cold climates, where biological interactions slow down considerably, where an ice cover can prevent access of atmospheric oxygen and sunlight to the system for months?

Needed: Increased Emphasis on Nutrient Removal and Bacterial Reduction and Concern About Lagoons Coping with Ammonia and Hydrogen Sulphide

The suitability and applicability of lagoons as effective wastewater treatment systems have been enhanced by

- modifying the construction (multiple-cell configurations),
- chemical addition for nutrient removal,
- marsh treatment of effluent, and
- add-on effluent-polishing filters.

With all these modifications and enhancements, at what point does the lagoon system cease to be a lagoon and become something else?

**2.1.2 Public Health Officers.** Satisfactory lagoon performance cannot be measured solely in terms of BOD and suspended solids removal. A clean-looking effluent with low BOD and suspended solids does not guaranty, after initial dilution, that the receiving stream is a safe source of water for domestic or even recreational use.

Lagoon performance is then satisfactory when it poses no problems to public health. With conventional lagoons that occurs when clean-looking water can pass the tests for the absence of pathogenic microorganisms that have a direct effect on public health; namely, bacteria, viruses, protozoa, and helminths (intestinal worms).

With aerated lagoons that occurs when the aerosols generated during aeration are free of pathogens.

## Needed: Criteria for Judging the Public Health Safety of Effluents

We test for the absence of pathogenic microorganisms by looking in an effluent sample for indicator organisms, usually E. coli. The absence of E. coli leads us to conclude that all causal agents for enteric diseases have been destroyed. That is not a valid conclusion, because E. coli does actually not satisfy all the criteria of an indicator organism. In a lagoon environment, viruses, such as the polio virus, survive three times longer than E. coli and streptococci. Viruses are regularly found in lagoon effluents. Therefore, the adequacy of E. coli as an indicator organisms has justifiably been questioned.

Cold-climate lagoons somehow seem to contribute to the longevity of microorganisms. One hypothesis is that lagoons allow microorganisms to escape thermal shock by allowing them time to acclimatize to the cold environment. Whatever the reason, microorganisms remain viable in cold-climate lagoons and receiving waters for long periods. Hence, large numbers of pathogenic bacteria are being discharged into the environment, generally directly into receiving waters. To this public health dilemma add the resistance factors (R factors) which render microorganism resistent to antibiotics, toxins, heavy metals, and ultra-violet light - much of the bacteriocidal arsenal. This resistance is derived from extrachromoso-genetic structures of DNA in a group of plasmids and transferred from cell to cell on contact. The implications to public health loom large.

## Needed: Effective Means of Removing Causal Agents of Enteric Diseases

Treatment of sewage by primary sedimentation removes bacterial pathogens ineffectively: the removal rate is no more than 20 to 40 percent. However, with one passage through a lagoon, 90 to 99 percent of indicator (E. coli) and pathogenic bacteria (Salmonella) are removed. But viruses are not completely removed by lagoons.

The emphasis of our concern should therefore be on the removal of viruses from lagoon systems, bearing in mind some of the factors:

- temperature and solar radiation,
- short-circuiting,
- pH,
- flocculation/coagulation/sedimentation, and
- filtration.

And that concern should be directed, above all, to lagoons associated with temporary work camps and individual homes, and to natural lakes that have been converted to lagoons.

Needed: Means to Assure Operator's Safety in the Form of Education and Training

### 2.1.3 System Owners

**Small lagoons.** The Department of Indian and Northern Affairs has constructed approximately 160 lagoons most of which are operated by Indian Bands. These lagoons serve populations of generally less than 1000.

Ultimately all of the individual wastewater treatment systems are to be transferred to the Indian Bands who will then become wholly responsible for their satisfactory operation and maintenance.

Lagoons for small communities should be easy and cheap to construct and operate by nontechnical persons.

Needed: New Design Criteria Suitable For Small Lagoons

What is needed are design specifications that take carefully into account:

- size and configuration needed for treatment,
- accurate design flows and loadings particularly during early years,
- rates of evaporation and infiltration,
- storage period required for seasonal discharge,
- freezing of inlet and outlet pipes,
- bank erosion prevention methods, and
- short-circuiting due to density currents.

**Large lagoons.** The City of Winnipeg has one lagoon which, when constructed in 1964, was designed for $13.6 \times 10^6$ L/d, but has since been downrated and is now treating $9.2 \times 10^6$ L/d.

Needed: Odour Prevention and Control

Erosion poses an operational problem, but the problem causing more concern is the public concern during a few days in the spring, when part of Winnipeg is overcast with the odour from the city lagoon. Originally the lagoon was situated outside the city, but over the years the city has expanded to within a whiff of the lagoon. The city is currently studying alternatives to the lagoon to assuage not only the public concern but also the pressure to develop the lands near the lagoon.

However, if the lagoon were to remain operational, what would be needed is a cost-effective method of predicting and dealing with the odour during the springtime.

### 2.1.4 Consultants

Needed: Conclusive Information About Lagoon Characteristics

A few areas about which more conclusive information is needed are:

- lagoon performance at different times of the year;
- intercell treatment efficiencies as influenced by type, size, and configuration;
- lagoon performance (treatment and odours) as a function of depth;
- lagoon discharge timing procedure:

  Which is best: the slug spring discharge (a poor-quality effluent) which receives high dilution; or the slug fall discharge (a good-quality effluent) which receives lower or no dilution; or a continuous summer discharge?

- leaking lagoons:
  - their acceptability,
  - choice of slow-infiltration liners over expensive liners,
- odour control:
  - effect of industrial waste discharges on odour control,
  - effects of sulphide and ammonia levels, and
- frequency and method of sludge removal.

Needed: Comprehensive Guidelines for Lagoon Design and Operation

Once more knowledge about lagoon design has been acquired, comprehensive guidelines or standards need to be developed. Most standards that do exist seem arbitrary, varying from province to province. For example, nowhere else but in Alberta is it required to incorporate anaerobic ponds. Objective: that recommendations initiated at this Workshop will be incorporated in the regulatory standards across Canada.

Besides standards that seem arbitrary or only regionally applicable, some may miss the true concern altogether. For example, the siting standard typically stipulates a minimum distance between a new lagoon and an existing built-up area. This minimum distance has often proven inadequate, because some communities tend to grow toward the lagoons and odour complaints may increase. Even with stipulated minimum distances, odours from a lagoon may seasonally reach a community. Placing lagoons beyond stipulated minimum distances is a matter of good planning.

The current trend in standards for lagoons favours greater stringency. But the basis for these standards does not seem to be clearly supported with facts.

Standards do simplify the work of consultants; however, there is a risk in blindly accepting all standards when other approaches may be better.

**2.1.5 University Professors.** The lack of knowledge about lagoons has led to actions that sometimes defy comprehension:

- lagoon theory relevant for Texas was applied to the design of a lagoon for Point Barrow, Alaska, the most northerly portion of North America;
- a prairie city provides phosphorus treatment of its lagoon effluents to control algal blooms in the receiving lakes, even though the lakes receive massive groundwater inflow containing from 5/100 to 25/100 ppm of phosphorus;
- additional lagoon cells (reduced loadings) were recommended to alleviate odour problems;
- lagoons are left unoperated because owners/operators think lagoons require no operation;
- bacterial count is used by public health officials to substantiate the need for improved treatment; and
- testing of lagoon effluent quality by environmental departments just prior to discharge into a dry water course.

Needed: Technology Transfer Sessions

Meetings such as this are needed to dispel the untruths about lagoon systems and to talk about some of the truths.

Needed: Year-Round Lagoon Research

- Lagoon field studies should be carried on year-round even when the conditions are unpleasant; that is, amidst odour from lagoons and during the cold of winter.
- More research is needed on acceptable loading rates.

## 2.2 Sessions on Lagoon Theory and Practice

**2.2.1 Lagoon Theory.** A lagoon is probably one of the most complex treatment processes. Unlike activated sludge systems, both aerobic and anaerobic microbiological processes occur in lagoons. Not only bacteria, protozoa, and rotifers, but algae are also present - at least during part of the year. There are many types of lagoons with many treatment objectives; very short-term, aerated systems at one extreme to total-retention systems at the other. All these organisms function as one system, the complexity of which makes a fundamental and comprehensive understanding of the chemical and biological interrelationships very difficult.

Essentially one has to ask oneself: Do we need to know more about lagoon theory? If not, how is lagoon operation to be explained better?

Is it desirable to have a fundamental understanding about the system? If so, what type of information needs to be acquired?

Can the costs of gaining such fundamental understanding be justified?

We have no guaranties that designs based on a fundamental understanding result in better lagoon performance.

We know much about lagoon design and construction, but our knowledge is not quite so extensive about:

- monitoring programs,
- lagoon operation,
- the chemical and biological processes underlying lagoon performance,
- design alternatives to accommodate given objectives of the operating system,
- natural disinfection processes, and
- dynamics and the change of rates; i.e., past inputs into a lagoon system which influence present performance, and time-dependent factors, which are a function of the seasonal environmental changes.

To be able to design lagoon systems from fundamental principles; i.e., a fundamental understanding of all chemical and biological principles, we need considerably more information. We require:

1) an understanding of its biological, physical, and chemical processes, and
2) knowledge about the physical configuration of the systems to ensure a design of the cells that gives a flow regime closer to plug flow.

Designing from fundamentals. We generally agree that basing the design of lagoons on fundamental principles is desirable, but more so for designing aerated lagoons. The performance of aerated lagoon systems can only be optimized by designs sensitive to the process taking place in them. But with total retention systems the construction constraints and the geotechnical constraints are more important than the biochemical processes.

For more knowledge pertaining to long-term retention lagoons, we should consult recent data collected by Alberta Environment (Appendix C) which represent one of the best monitoring investigations into such lagoons. The results of that investigation will influence how lagoons will be designed and operated.

With this and all the other existing information, we don't need to pursue the fundamentals of what is taking place in long-term retention lagoons much further.

For sources of information that can contribute to a fundamental understanding underlying lagoon systems (or that type), some workshop participants have suggested that we look to limnology, aquaculture, and microbiology, especially that of psychrophilic and psychrotrophic bacteria.

Whatever further knowledge each of us acquires needs to be shared. One possible vehicle is the development and maintenance of an information summary document for use by designers and operators of lagoons. Such a document would perhaps be better than a design manual or a publication of that sort, because the diverse types of lagoons and the diverse treatment objectives cannot be adequately accommodated in any one manual.

Comments from the floor. Several concerns were expressed in the course of the discussions. By way of acknowledgment they are listed here:

- effect of temperature on microorganisms;
- effect of snow on light penetration into a lagoon system;
- r factors and their applicability to winter conditions;
- odours and their causes;
- differences in the nature of the suspended solids in the influent, effluent, and benthos;
- short-circuiting in conventional and aerated lagoons;
- determination of the rate coefficients used in lagoon systems;
- relationships between indicator and pathogenic microorganisms;
- parameters to be monitored to verify lagoon performance requirements;
- alternative, non-chemical methods for reducing effluent phosphorus levels; and
- excessive sludge buildup and methods of sludge removal.

### 2.2.2 Lagoon Design and Operation

**Site selection.** Site selection is one of the most important functions in lagoon design. It requires the following considerations:

- geotechnical analysis, especially in permafrost areas;
- isolation distance;
- leakage through berms and seepage into the groundwater;
- wind direction, waste mixing, berm erosion, and odour potential;
- availability of materials for construction; and
- topographical and hydrogeotechnical information (town official(s) can supply information about groundwater, etc.).

**Process design.** "Of all the designs of biological treatment processes the design of stabilization ponds is perhaps the least well defined." - from modern textbook (Metcalfe & Eddy Inc., Wastewater Engineering, 1 ed., John Wiley & Sons Inc., New York, N.Y.). Before we can say what research is required, what the design should be, or what the problems really are, we need first:

(a) more and better data on the performance of existing lagoon i.e., we need data on

  - loading,
  - effluent quality,
  - toxic substances,
  - microorganisms, and
  - geometry.

(b) handling procedures for accumulated sludge in both anaerobic and facultative lagoons;

(c) standardization of design techniques incorporating

  - design loading,
  - retention times, and
  - kinetic equations.

(d) information of civil design techniques, especially about berms (berm performance) and special structures pertaining to lagoons

- in continuous and discontinuous permafrost;
- in most soils above 60° latitude which are unsuitable for lagoon design; they pose problems because they are highly saline and ice-rich and therefore difficult to compact; and
- during short construction seasons.

**Size of population as a limit.** There is no cut-off point after which the size of the population is so great that lagoons become an inappropriate means of wastewater treatment. If there is a cut-off point, it has to do with economics: the cost, availability, and utility of land.

### 2.2.3 Upgrading Lagoon Systems

**Practices in Ontario.** Steve Black reviewed several case histories of upgrading lagoons in Ontario:

- phosphorus removal from continuous-discharge and seasonal-retention lagoons by the addition of chemicals into the influent or lagoon contents;
- control of hydrogen sulphide by installing static-tube type aerators into secondary lagoons;
- control of eutrophication and ammonia toxicity in a trout stream by installing an aeration cell and exfiltration cells; and
- control of dissolved oxygen in the receiving water by the addition of an aeration cell and several sand filters for high BOD and ammonia removal.

Pilot-scale studies were carried out before any of the upgrading options were implemented as full-scale projects. Ontario's experience shows that various means for upgrading the quality of effluents are available; some of them are site-specific.

**Aquaculture.** Through aquaculture, nutrients can be removed from ponds. Some of the marketable by-products help in defraying O&M costs.

Duckweed can metabolically take up as much as 3 percent phosphorus and 8 percent nitrogen from the effluent and thus lower its nutrient concentration. The duckweed can be regularly harvested and used to supplement animal feed.

Some researchers in the U.S.A. are experimenting with bio-webs on which biological grazers can lodge and feed on bacteria. Other researchers are testing the effectiveness of microstrainers as effluent polishing equipment. These microstrainers could serve as tools in harvesting biological production.

Where high-quality effluents can be produced in lagoons, without the addition of chemicals, the lagoons can be used to grow fish to a size suitable for replenishing waters depleted of that species of fish. John Neil spoke of his participation in an experiment in such fish culture. These fish contributed to further improvement in effluent quality in the lagoon.

**Wetlands treatment.** Natural wetlands may be ideally suited for receiving lagoon effluents for further treatment in the course of which BODs, suspended solids, and nutrients are removed. (Ontario has experienced a problem with hydrogen sulphide in some of its wetland systems.) However, regulatory agencies may not yet be convinced that this is an acceptable method of upgrading lagoon systems.

With peat bog wetlands treatment, effluents from a septic tank have been purified to drinking-water quality after flowing through about 1 km of peat bog, according to Yves Dubuc, who with Montreal's École Polytechnique conducted a 4-year study into this subject. Wherever this type of treatment is used in Canada, the results have been satisfactory: good removal of BODs and suspended solids; and the effluents contain neither phenol nor hydrogen sulphide.

**2.2.4 Aerated Lagoons.** A number of different aeration devices are available for surface and sub-surface aeration. For cold-climate conditions with operation under ice cover, the diffused air from submerged aeration devices is preferred over surficial, mechanical aerators in municipal wastewater applications. Dissolved oxygen concentrations achieved with these aeration devices under ice and snow cover for Ontario lagoons were reported.

These aeration devices are used in completely mixed, aerobic, aerated lagoons and incompletely mixed, facultative, aerated lagoons.

Participants shared their experiences with the design and operation of aerated lagoon systems:

- Environment Alberta reported two comparative sub-surface aerated lagoon systems to be operating quite well. Both have a small, completely mixed 3- to 4-day retention pond followed by 25-day facultative aerated lagoon of less intense aeration and approximately 4 days of polishing without aeration. One system is equipped with static-tube aerators, and the other with diffused-air tubing.

- The design method used by the Municipal Wastewater Management, Ministry of the Environment of Quebec was described as well as the studies conducted on its behalf by École Polytechnique to determine working values of the coefficients K and θ used in the design method. Field data obtained over three seasons at one aerated lagoon site in Quebec failed to give a good correlation between the laboratory values and the actual calculated values of K and θ.
- It is difficult to replicate K values, even in the laboratory by using the Warburg respirometer and BOD methods, because the tests themselves influence the results.
- Dr. Thirumurthi reported good correlation of field results in P.E.I. with his design method when treating municipal wastes using a standard loading and K and θ values determined from laboratory studies.
- When dealing with unknown wastes affected by industrial discharges laboratory studies are essential to approximate the reaction rate coefficients and other correction factors used in the design models.
- Acceptable phosphorus removal can be achieved in aerated lagoons by chemical addition, with alum being the preferred coagulant. A linear relationship exists between phosphorus removal and the coagulant dosage that can be used for design.

**Completely mixed aerobic aerated lagoons.** While satisfying the oxygen demand, there is sufficient energy applied to maintain all the organic solids in suspension which results in a completely mixed flow pattern. Aerobic aerated lagoons must be followed by other cells for solids separation.

**Incompletely mixed facultative aerated lagoons.** While satisfying the oxygen demand, there is insufficient energy applied to maintain all the organic solids in suspension. Although the top layers remain aerobic, the bottom layer presents an anaerobic environment.

**2.2.5 Aerobic/Facultative Lagoon Models.** Lagoon models attempt to simulate the reactions that take place; they represent a rational means to determine lagoon performance and operation strategies. The desired model must be based on sound theory but not be too complex to be practical. Unfortunately precise formulas are not currently available to account for the known factors that influence performance.

The Thirumurthi model, which has received some recognition, is based on steady-state, continuous flow in warmer climates, without ice cover. It recognizes organic load, dispersion, detention time, solar energy, temperature, and influent toxicity; but not pond depth and benthic load. At standard environmental conditions of 20°C and an organic load of 67.2 kg BOD/ha•d, Ks, the first-order BOD removal coefficient, is in the order of 0.056/d; and $\theta$, the temperature coefficient, is about 1.036.

With ice and snow cover the reduced incident light energy results in decreased dissolved oxygen concentrations; and at greater depths, reduced BOD removal efficiency. Dr. Thirumurthi's model does not account for these conditions.

The temperature coefficient r is not constant. Little is known about its variance at low temperatures (<10 to 12°C) so it must be determined in the laboratory for each specific case.

Dr. Thirumurthi does not expect that we will ever have a precise equation, but with computerized dynamic models it should be possible to come within plus or minus 20 percent of actual performance.

With the present state-of-the-art, in most cases reasonable designs based on experience with successful installations are more acceptable than working with design models and assumed values for their variable parameters.

## 2.3 Getting On With It: Elements of a National Cold-Climate Lagoons Research Plan

**2.3.1 Objective of Future Research.** Better and more reliable performance of lagoon systems at affordable costs.

Attaining this objective requires:

- a fundamental understanding of the physical, chemical, and biological interrelations occurring in lagoon systems; and
- more knowledge of the significance of the physical configuration, including the number and depth of cells.

This information can be used for:

- rationalizing the fundamental factors affecting lagoon performance to serve among other things, modelling; and
- developing criteria for small- and large-capacity systems with continuous, intermittent, and no-discharge operational modes at short or long retention times.

**2.3.2 Identifying the Research Needs.** The previous 5-year research program at the Universities of Toronto and of Alberta and École Polytechnique divided the research into lagoons into six basic areas, each associated with a number of topics:

To start the process, D. Smith distributed copies of the 42 project topics previously referred to in Section 1.2 to each workshop participant. Based on deliberations during the previous 2 days, the participants added another 23 topics for a total of 65.

Once the list had been compiled, each participant was asked to select what he considered the 10 most important topics and to rank them in order of priority. (See Appendix C.) (The 10 projects of greatest importance and interest to the participants are listed in Table 1 in Section 1.8.)

**2.3.3 Discussions Arising From Identification of Potential Topics in Research Projects.** In this part of the Proceedings the key points raised during the workshop on project topics are recorded, as well as the responses to them by other participants during the Friday morning session under the theme: "Getting on with it".

Proper data collection is imperative, particularly when operating standards and guidelines are to be derived from them. Information gained through laboratory work and monitoring in the field is valuable in establishing the practical relationships basic to procedures for the design and operation of lagoons. The data gathered for lagoons in Alberta are a model for the sort of information that should also be collected for lagoons in the Northwest Territories and the Yukon. No data have been collected for northern lagoons, yet one can expect significant differences brought on by adaptation to climatic and geotechnical conditions.

Data collection of samples of effluent quality are needed to show whether waste treatment systems comply with regulatory requirements. When sampling is done to verify the validity of the effluent criteria themselves, some jurisdictions consider this research and look for funding elsewhere. When sampling is done to demonstrate compliance, it costs much money, say, $500/facility for each sample to test for BOD, suspended solids, and total coliform; i.e., the basic sanitary engineering parameters.

The lack of data from northern lagoons can be rectified with regulatory agencies' making sampling programs part of their license requirements.

In the past, neither human nor financial resources were made available to collect data in the North. Also, with the distances between communities being so great, monitoring programs are difficult to institute. That difficulty may be overcome in the future with improved air travel.

A problem in collecting information on the design, configuration, and performance of lagoons in the Yukon Territory was mentioned. About a dozen lagoons have been operating in the Yukon Territory. Some of them have been expanded over the years with varying designs because every consultant imprints his own approach onto the design to such detail even as the material used. The information collected should include the types of connecting and effluent structures used. It should also include statements from operators, statements about the good and bad qualities of their particular lagoon.

A request for filed data should be directed to provincial and federal agencies by sending standardized forms showing the information desired. The forms should be designed so that the information is easily transferable to computerized storage. Some provinces, such as Alberta and Ontario, are implementing data processing computers.

The accumulation of data does not guaranty its being used. Money may be better spent on studying representative systems than on collecting data on a 1000 systems, data of doubtful usefulness at that. Systems should be identified from which the desired information can be derived.

Until there is some uniformity in the sample collection techniques, the value of the data has to be questioned. This uniformity can overcome the diversity in the types of lagoons, otherwise the compiled data may not be valid.

Until 1982, Ontario Ministry of the Environment issued operations reports which gave a description of the system, a sketch of the system, an operating description, and the performance data over the previous years. These reports are no longer being published. The operating data still being collected, however, are not stored on computer facilities. (The physical characteristics of the systems are not reported). Even for these rather detailed past operations reports it would be necessary to go back to the original records, many of which are no longer readily accessible to make a proper assessment of the data they contain. The significance of the data has to be verified before it can be relied upon for use in establishing design/performance criteria. This will not be easy to do.

Reference was made to the effort expended to obtain the data contained in EPS Report 5/UP/1, December 1984, "Operation and Maintenance Costs for Municipal Wastewater Treatment Facilities in Canada - 1980". It proved to be a significant task just to compile the data, get it on computers, and do some preliminary analysis on about 50 facilities surveyed.

Ontario and Alberta may each have more than 100 lagoons for which operational data is available. With proper selection, good data could be obtained from relatively few installations, and general conclusions drawn from them.

**Developing monitoring standards (Projects 44, 45, 54, 61).**

Standardized Sampling. (Statistical analysis of field data and guidelines on its interpretation and use for design and performance of the various lagoon options.)

Specific effluent objectives must be established before proceeding with a design.

With a uniform method of collecting information, data can be used with confidence by researchers to develop meaningful models and to interpret them so that they can be used by designers to achieve the desired lagoon performance.

Analysis. Guidelines should be established:

- for data-collecting so that the data that become available are suitable for analysis; and
- for good analytical methods, including methods for averaging data (arithmetic, logarithmic, and geometric means) so that the analyzed data lends itself to proper interpretation. There are doubts about the validity of the standard BOD test as a means of evaluating lagoon performance. Other tests, such as total organic carbon (TOC) and total oxygen demand (TOD), may be more appropriate.

**Odour control and prevention (Project 33).** Odours from lagoons are the major source of problems that lagoons cause the general public. In the past, sewage lagoons could be built far away from communities, but nowadays the land may no longer be available. Knowledge about odour control is necessary if lagoons are to remain the most economical wastewater treatment systems.

The processes in odour generation have to be known; i.e., the roles played in these processes by the type of waste, the size of the lagoon, and the weather. Methods for both the quantitative and qualitative assessment of odour intensity in the field still need to be developed before a proper assessment of odour control methods can be carried out. Once all this is known, the design and operation of a lagoon can be rationalized to curtail odour generation.

**Evaluation of indicator organisms representative of the presence of pathogens (Project 46).** E. coli as an indicator organism does not satisfy all criteria. The adequacy of E. coli as an indicator in cold water has been questioned. Besides bacteria, wastewater contains other enteric pathogens including viruses, protozoa, helminths, and bacterial mutants. The mutants are responsible for acquired resistance to antibiotics. We need confirmation that the presence and number of fecal coliforms bears a relation to the presence and number of pathogenic bacteria. Viruses and protozoa are not well represented by using fecal coliform bacteria as indicator of fecal pollution.

**Definition of the biokinetics in a lagoon under ice cover (Project 1).** In the past the majority of studies on lagoon operation and performance has been carried out during periods of favorable weather, when lagoons are readily accessible. As a result we do not have much data about lagoons under ice and snow, generally under harsh winter conditions.

In early spring, once the ice cover is off the surface, natural mixing frees gases that have been formed anaerobically during the winter. We need to know more about these gases to control the odours associated with them. Ice and snow cover reduce the amount and depth of sunlight penetration which along with the cold temperatures restricts the growth of algae. Hence, these conditions also restrict natural disinfection. Ice and snow covers stop the transfer of oxygen from the atmosphere, yet dissolved oxygen has been measured under the ice during Ontario and Quebec winters. Most of the rate coefficients for the empirical/analytical design models have not been investigated at lower temperatures. Once the temperature is below 7 or 8°C, these equations are no longer valid because the correction factors have not been determined for temperatures below 7°C.

Some investigators have studied changes in microbial activity rates when the dominating populations change from mesophiles to psychrophiles.

Much more needs to be known about the biokinetics of cold-climate lagoons under ice cover before we can improve winter performance and prevent objectionable odours during springtime.

**Design criteria for small lagoons (Project 49).** Can we design lagoons to serve small populations (100 to 400 people) by scaling large systems down, or do we need to design according to different criteria?

For example, above the tree line in Northern Quebec there are small communities on the Canadian Shield in permafrost. The landscape is characterized by lots of rock outcrops and little soil. It is not feasible to install piped sewage systems for these small populations. Populations of at least 800 people are required to justify piped sewage systems financially. Sewage is collected by truck haulage from residential holding tanks. Here lagoons are subject to complete freezing in the wintertime with at least 1.8 to 2.2 m of ice cover. The hauled wastes are discharged on top of the ice making layers of frozen wastewater.

The questions are:

- how will the biomass react in the spring, and
- will the lagoons have difficulty in reestablishing themselves? Unlike other lagoons where a certain level of water remains during winter, for these lagoon, which freeze completely, there is no seeding.

Northern communities have many special problems with their lagoon systems because the volume of sewage is low and because the severe cold prevents the use of subsurface inlet and outlet devices.

The Ministry of Indian and Northern Affairs is the owner of numerous small lagoons for which the concerns associated with large lagoons do not apply; e.g., future expansion, flexibility, sludge, disposal, industrial influences, and erosion protection. Therefore, design criteria specific to small lagoon systems would prove very useful.

**Design criteria to optimize pathogen removal (Project 56).** Bacterial reduction is one of the major aims of lagoon systems in the North. There is a need to develop design criteria to optimize pathogen removal. As in some southern countries, effluents require maturation ponds with shallow depths to increase natural bacterial reduction. We need some design criteria stating what kind of cell or treatment is needed in the system to improve pathogen reduction before discharge. Can we take better advantage of the natural disinfection processes occurring in lagoon systems or must we rely on more costly chemical disinfectants and ultraviolet radiation?

**Use of wetlands or other aquatic components to upgrade lagoon performance (Project 39).** The discharge of lagoon effluents into wetlands for nutrient removal and polishing can yield good results. Natural wetlands treatment is being studied in Saskatchewan, the Northwest Territories, Ontario, and Quebec.

The feasibility of using artificial wetlands to upgrade lagoon effluents has been studied in Ontario, Saskatchewan, and British Columbia. Experience with these systems in Ontario shows some problems in design and operation primarily concerning the presence of ammonia, phenols, and hydrogen sulphide.

The deliberate planting of duckweed, sedges, cattails, and other suitable aquatic plants including artificial plastic materials could result in a modification of the whole ecosystem of sewage lagoons. They provide surfaces to which bacteria and other biological grazers can attach themselves rather than settle at the bottom of the lagoon.

More work is needed on these aspects and on the economics of removing and utilizing the resulting plant production.

Similarly, information on fish culture in cold-climate lagoons is sparse. The study of fish culture in the lagoon at Port Perry, Ontario, showed surviving pickerel fingerlings to weigh about 26 g by the end of the season. At this size they are eating fly larva and daphnia. With the refinement of such procedures, these small fish could be harvested and used for restocking streams where their species have been unduly depleted.

**Dynamic model of lagoon process (Project 47).** We may never arrive at a model or equation that will predict precisely the effluent quality, but one that predicts with 20-percent accuracy should be attainable. That model can then be improved over the years, provided the study is funded for at least a 3-year duration, rather than a series of studies each lasting 1 year.

The biggest problem we have is that most of the studies we have undertaken so far have been, inadequate, short term, insufficiently funded. As a result we end up with many pieces of incomplete research here and there.

The project should include laboratory model studies where variables can be controlled, monitored, and compared more quickly and more conveniently than in the field. The laboratory results plus literature data would go into data storage and into computer programs to improve not only the laboratory studies themselves but also the models.

The next step would be to investigate experimental lagoon systems on a pilot scale and with an intensity similar to that given by the City of Winnipeg to its aerated lagoon study in the late 1960s and early 1970s.

With good interaction between laboratory research, data analysis, theory development, and pilot field studies, the next step would be to design and build a demonstration system followed by intense monitoring and analysis of data as has been presented by Environment Alberta at this workshop.

At the outset we must establish the effluent quality objectives. To establish them we need to sort out the relationships between, theory, effluent quality design (numbers), and the actual numbers. Then it becomes a question of how much fine-tuning of the numbers can we afford financially.

In Alberta, the effluent quality with the fall discharge is higher than the numbers in the effluent objectives. To what extent can we back off on that in terms of fine-tuning the operation? What can be fine-tuned anyway? Once the size of the reactors has been established and the reactors installed, the operating conditions of the system cannot be changed, given the long retention times. We are bound by existing procedures: if they call for 22.4 kg BOD/ha•d, that is the number we use in the design. That leaves little room for fine-tuning. We have to look at programs on a national environmental scale. We have to look at programs and the priorities of specific programs and then decide where we should put our resources. The research components must have an impact on operating systems.

Certainly, it is very difficult to exercise control over the operation of a system, once it has been installed. But what we can nevertheless control are:

- discharge time,
- discharge mode,
- depth of the system, and
- loading on the system per unit area.

This gives fairly crude control over the system, but still control.

There are and will be many different types and approaches to lagoon design, each adapted to work in the diverse regions of Canada. In the prairie regions, where land is plentiful the opportunity exists for storage of 12 months or longer. Therefore long-term retention lagoons are the solution. In regions where land is at a premium, other types of lagoons have to be considered, often aerated lagoons.

So, there is room for investigation or at least quantification of what is happening to see whether additional work is needed in improving the designs of some of these other lagoon systems.

**2.3.4** **Summary.** During this session, program areas were identified by priority for inclusion in the National Cold-Climate Lagoons Research Plan. The concensus reached at this workshop has been recorded in the Proceedings for consideration not only by the workshop participants, but also by those unable to have attended it, yet also concerned about the future role of lagoon systems in cold-climate regions.

In Section 2.4, the suggestion for follow-through and support activities over the next years have been recorded. Accompanying each suggested activity is the mechanism required to implement it. All activities constituting the program require human and financial resources from interested parties in governments, university, and private industry.

The first step is to bring together a representative co-ordinating body to develop and implement the National Cold-Climate Lagoons Research Plan.

## 2.4 Identified Post-Workshop Activities

To implement the National Cold-Climate Lagoons Research Plan requires committed dedication from all participants at this workshop.

### 2.4.1 **Organization.** Implementation must begin with the formation of a body - a standing steering committee - that is responsible for developing and managing the National Cold-Climate Lagoons Research Plan.

**Composition of the steering committee.** To be able to cover all interests in the advancement of lagoon technology, the ideal composition would encompass representatives, chosen from among the workshop participants, of major sectors and regions.

**Activities of steering committee.** The following activities would pertain to the implementation of the 10 top-ranked projects and the related technology-transfer functions:

- finalize the Plan and delegate the activities associated with it;
- coordinate and administer the delegated activities;
- encourage participation by operators;
- conduct semi-annual progress reviews either nationally or regionally;
- encourage quarterly reporting of project progress and other lagoon-related news;
- develop a central databank and an information retrieval system; and
- publish "hands-on" manuals for cold-climate lagoon design, construction, and maintenance;

### 2.4.2 Objectives of Entire Organization:

- to discuss problems of and new approaches to lagoon design, construction and operation with the aim of improving the performance and reliability of lagoon systems;
- to gather and package existing information for distribution to designers and operators;
- to respond to the diverse needs in various regions of Canada;
- to recognize the political nature of regulatory changes; i.e., to weigh the needs and benefits against the cost of change;
- to gain a better understanding of the biological and physio-chemical aspects of the processes in a lagoon;
- to apply that improved understanding to the mathematical modelling approach to design.

**2.4.3 Strategy.** Money and effort will be spent on studying a representative number of lagoon systems rather than collecting and compiling old data that may no longer be very useful.

The in-depth, year-round study of a representative number of lagoon systems will be the source of data for collection and analysis.

Even though we may agree on a technical innovation, often there is a great deal of lag time between the conception of the idea and the time you realize some change. People often become discouraged along the way. Appreciating the slow pace that will naturally take place helps in not becoming too discouraged. We have to go in for the long haul, not the short run.

**2.4.4 Priorities.** Because all 65 recommended research projects cannot be implemented, general areas of priority have to be identified. These areas of priority must be matched with persons expert in them.

The progress of research and study into areas of priority must be monitored. Where the progress does not meet expectations, we must find the cause and remedy.

We need to identify areas of priority in response to current needs and problems. Given that these needs and problems can change with time, we must have a mechanism whereby the areas of priority can be updated correspondingly.

With our planning to submit 25 representative lagoon systems to in-depth studies, the item of highest priority must be a compilation of a summary of individual lagoon systems; i.e., a list of all lagoon installations, so that we can choose those 25 representative lagoon systems properly.

**2.4.5 Activities:**

- devise a plan for implementing the research program;
- report every 3 months on projects in progress;
- hold an annual review of progress by the steering committee;
- hold regional/national workshops/conferences as new knowledge is gained;
- review goals and direction of program at such workshops/conferences;
- publish:
    - list of published material on display,
    - literature updates,
    - lagoon newsletter,
    - project update sheets, and
    - summary of all lagoon systems.

### 2.4.6 Suggested Responsibilities for Delegation by Steering Committee.

- Responsibility for implementing studies on existing lagoon systems:
  - (a) to document performance and effluent quality from seasonal discharges (Project 26),
  - (b) to document problems and innovative solutions (Project 27).
- Responsibility for co-ordinating activities to meet the identified needs relating to:
  - (a) lagoon operation and maintenance (Projects 44, 45, 54, 65),
  - (b) biological and physio-chemical aspects of lagoon system theory and design (Projects 1, 39, 49, 56).
- Responsibility for information exchange by publication and by dialogue through a spectrum of useful activities, some of which are outlined in 2.4.5. This area of responsibility could include a literature review. A literature review is available, but it requires updating regularly to ensure that research work is not duplicated. That means that those performing this responsibility must:
  - appeal to various governmental agencies to respond to both the list of priorities and the potential follow-up programs with financial support;
  - ensure that a certain number of the identified priority activities are carried out or, at least, initiated in the next year;
  - organize regular meetings as warranted by interest and necessity; and
  - issue summary information about the research areas, since the preparation of a design manual will not be undertaken at this time.

**2.4.7 Making a Commitment.** With the needs and priorities established, those people working in the field can think through all these areas of responsibility and the various activities associated with them, and decide how they can best contribute.

### 2.5 Closing Statements

To wrap up the formal session of this meeting, we have asked representatives from governments, consulting firms, and universities to give some closing statements.

**Government regulators.** Government regulatory authorities recognize the need for new ideas and information useful for the development of guidelines and regulations. We must also recognize that:

- needs differ from region to region because of the diverse geographical characteristics;

- regulatory changes are determined at the political, not the technological, level; and
- lag time between innovative ideas and their implementation fosters discouragement which needs to be overcome.

**Consultants.** More than half of the municipal wastewater treatment systems in Canada are lagoons: there are more than a 1000 lagoons, mostly in the western provinces. Yet our knowledge about them is quite primitive. Sixty-five research projects have been identified to rectify that situation. Since not all these projects can be undertaken, priorities according to areas of expertise must be established. Each of us has to decide on the greatest contribution he can make to promote the goals we have set for ourselves.

The interest developed at this workshop must be maintained. In 2 years we should meet again for the following three reasons:

1. to report on progress (a technical update);
2. to deal with problems hindering progress in priority areas; and
3. to identify new needs and update priorities.

This workshop has already been the source of ideas for immediate use in the design of lagoon systems; e.g., the ideas presented on nitrogen removal by using extended aeration will help in coping with this increasingly stringent effluent criterion.

This workshop presented an excellent forum for an exchange of ideas. In the process we learned

- what work is being done in university, industry, and government; and what work will have to be done;
- where to find more information on lagoon systems, information specific to Canada; and
- about design concerns.

At future workshops, hopefully, solutions to design problems, such as bacteria reduction and odour control, will be presented. In the meantime, we need to have a regular update on the progress of research, possibly through an annual newsletter and a periodic abstract of ongoing research.

**University professors.** Much of the discussion at this workshop centred on open-water situations. There is a great need to know what is happening in ice- and snow-covered lagoons, the normal state for cold-climate lagoons. That need is not being met now.

Some questions raised here had already found answers in the past; for example:

- removal of algae from lagoon effluents (microscreening), and
- temperature coefficient (θ).

For other questions, such as how to control erosion, there are no answers yet.

We may think of lagoons as simple systems, but that they are not was revealed at this workshop.

## 2.6 Workshop Evaluation

At the conclusion of the workshop the participants devoted time to evaluate the workshop by completing an appropriate form. See Appendix F; it lists representative comments under the headings:

- comments on the success of the workshop,
- some shortfalls of the workshop, and
- comments on the organization of future workshops.

Participants thought that the workshop met its primary objective of identify priority areas for further study.

# 3 LAGOON THEORY AND DESIGN

## 3.1 State of the Art

**3.1.1 Lagoon Treatment Performance in Alberta.** Sewage lagoons (wastewater stabilization ponds) are and have been the most common form of sewage treatment in Alberta. In 1984, of 363 communities using some form of sewage treatment, about 297 of them use lagoon treatment. Sixty-five percent of the lagoon systems use the anaerobic-facultative type of treatment; thirty-five percent use single or multiple facultative cells.

Alberta's standard for lagoon construction calls for

- two or four anaerobic cells (where applicable), basically all multiple-cell systems are operated in series;
- one 2-month treatment cell; and
- a large pond with 12-month retention capability.

Currently 60 percent of the lagoon systems provide storage for 12 months.

An evaluation of the lagoon effluents was conducted on 364 samples collected between 1978 and 1983. The discharge of the lagoon effluents, from which these samples were taken, occurred in the spring, in April/May (generally at the time of spring runoff) or in the fall, October/November (generally after farming operations had finished).

In the spring, the storage cells are drained to about 30 cm above the bottom, so that the settled sludge is not disturbed. Where the storage cells are drained in the fall, the depth to which they are drained must allow for the freeze protection of the inlet pipes. (No attempt was made to monitor the characteristics of raw wastewater.)

The following conclusions are based on:

45 once-a-year spring-discharge samples,
49 once-a-year fall-discharge samples,
117 twice-a-year spring-discharge samples, and
153 twice-a-year fall-discharge samples.

For more details, see Appendix D-2.

Conclusions:

- All lagoons providing 12 months of retention produced effluents of better quality than those providing only 6 months of retention.
- Effluents of the worst quality occur where lagoons are discharged twice a year, because the wastewater undergoes little treatment during the winter months.
- With once-a-year and twice-a-year spring-discharge samples, those from the May discharge period show a significant improvement in effluent quality over those from the April discharge period. The reason is that in May the ice cover has disappeared and pond turnover is complete.
- Those lagoon systems with the configuration of four anaerobic cells and two or more facultative cells provide the best-quality effluents for both spring- and fall-discharge periods. None of the systems provide much treatment during winter.

**Study into continuous overflow.** Five lagoons were allowed to overflow throughout the summer, rather than allowing spring discharge. The overflow rates were progressively reduced:

| Month | Raw Flow (%) |
|---|---|
| April | 100 |
| May | 75 |
| June | 50 |
| July | 33 |
| August | 25 |
| September | 25 |

Some Observations:

| | | |
|---|---|---|
| BODs | - | in March/April, 50 to 60 mg/L (fairly high); in May (ice cover has disappeared and turnover has finished), <20 mg/L; |
| Suspended solids (SS) | - | in June, concentrations increased (possibly because of algal bloom); |
| Total nitrogen<br>Ammonia<br>Total phosphorus | - | in June, levels decreased significantly. |

Results. The effluent is improved. Lower organic nutrient loadings and volumes are released than those associated with the volumes and quality of spring discharges.

Discussion. To confirm this trend other factors, such as temperatures, evaporation, infiltration, seepage, and liquid level in spring, would have to be investigated.

More Results from That Study.

- Lagoon depths of less than 2 m provide better treatment than those having depth of 2 m or more;
- Effluents from storage ponds capable of providing a 12-month detention period seem unaffected by the depth of the final holding pond.

More Discussion. These findings should only be viewed as "indicative trends" because of the many variables involved. Some of the variables include:

- differences in the size and type of lagoon configurations,
- influent quality and flows,
- state of repair,
- time span of sampling,
- sampling errors,
- population differences, and
- number of results used in determining averages.

**Study to Measure Successive Stages Over the 2-Week Discharge Period.**

| Time | Concentrations of BOD and Suspended Solids in Effluent |
|---|---|
| After the first 2 or 3 hours: | rise |
| At the end of the first day: | drop |
| At near-end of discharge period: | unchanged |
| At end of discharge period: | rise, more so in the suspended solids |

The rise in the concentration of suspended solids at the end of the discharge cycle may be due to the bottom disturbances. The other parameters followed generally the same patterns.

All this information constitutes a significant set of data contributing to lagoon configuration and operating strategies that can be used in a model to produce a specified effluent quality.

The data verify that nitrification occurs during the summer months, a point on which three of the lagoon systems documented in EPA's "Design Manual and Municipal Wastewater Stabilization Ponds" (EPA-625/1-83-015) concur.

The data further concur with published data that show that most lagoon configurations with retention times of 3 months or less during the operational period have concentrations of BOD and suspended solids above the 30/30-mg/L range. This should be accepted in terms of meeting specific design limits.

**3.1.2 State of the Art vs. Design Criteria of Regulatory Agencies .** The objective of this presentation is to take a closer look at the significance of the design criteria advanced by the various regulatory agencies. Those effluent criteria vary from one regulatory agency to another.

On the basis on statistical data about the performance of lagoon systems, we want to determine whether the guidelines issued by certain agencies are realistic. We know that a BOD and suspended solids level of 10/10 mg/L cannot be achieved by any lagoon without some type of tertiary treatment. We also know that in cold climates, facultative lagoons that discharge continuously cannot meet the secondary treatment requirements applicable to mechanical systems.

**Effluent quality criteria for territorial regions.** The effluent quality criteria in effect in regions of the Northwest Territories are based on both the nature of the receiving stream and the nature of the discharge. The idea is to:

- define raw-sewage quality,
- assess what a lagoon would treat,
- take the effluent from the lagoon and apply it to the receiving stream, and
- determine whether the lagoon effluent actually results in the expected water quality at the edge of a mixing zone.

It works like this: we define an arbitrary mixing zone of 100 m. Then we speculate on modifying the extent of the mixing zone with additional criteria:

- fish must not die as they go through the mixing zone, and
- the edge of the mixing zone must meet the raw drinking water quality standard of <100 coliforms/L.

Unfortunately this approach has not proven successful, because we were not getting the expected removal efficiency. At Fort Smith or at Norman Wells, to conform to that raw drinking water quality standard, we would either have to increase the plume to 2 km or remove the coliforms by two or more orders of magnitude.

Generally expected removal efficiencies of a primary or anaerobic lagoon are:

40% BOD,
60% suspended solids, and
75% total coliform.

The lagoon for Yellowknife, N.W.T., produces effluents with:

30 mg/L BOD,
35 mg/L suspended solids, and
$<10^3$ coliforms/100 mL.

Yet, data presented from lagoons operating in the N.W.T. and Yukon show possible removal efficiencies of:

78% BOD, and
78% suspended solids, and
total coliform reductions of one order of magnitude less than projected.

This presents a problem for regulatory agencies, because they are caught between past, wrong guideline and a current need to upgrade the effluent quality from these northern sewage lagoons. The problem may be primarily a political one, and secondarily a technical one. Nevertheless, the two are closely linked. Therefore, our standards have to reflect the political expediency, and that requires the interpretation into technical expediency - which is the domain of process design.

With the application of these guidelines over the past 3 years, water boards have become more aware of the problems with coliforms, despite the limited data available, as an indicator organism for the presence of pathogens. The greater awareness arises from information about:

- transmittance of R factors, and perhaps a
- change in the coliform bacterium.

The Water Board is again looking at the guidelines but still without the benefit of the necessary database.

**Implementation of a dynamic, geographic assimilative approach.** This approach, to be successful, requires a program for monitoring compliance. Standards based on water quality generally require such monitoring. But to carry out such a monitoring program, in turn, requires enormous human resources (engineers, inspectors, administrators, etc.). Such scale of monitoring, however, cannot be justified.

**Federal Government's approach.** **The Federal Government's criteria for** effluent quality established for federal facilities are very stringent:

$BOD_5$: 20 mg/L
Suspended solids: 25 mg/L
Fecal coliforms: 400 per 100 mL (after disinfection)
(Membrane filter (MF method)

These are independent of the receiving stream and water quality. Conventional lagoon systems should not be expected to meet these criteria in the winter and only sometimes in the summer.

**Alberta's approach.** Alberta has about 300 municipal sewage lagoon systems. Most of them are licensed. The reporting requirement for the license to operate is critical because a regulatory agency has otherwise no means of ensuring that the objectives it sets are being met.

One of the objectives is to avoid overdesigning; for example, if a lagoon yields 8 to 10 mg/L (BOD or suspended solids), an increase to 12 or 13 mg/L could be tolerated, provided this increase results in lower costs as a benefit from some innovation in design. The standards are being revised now. The revision may be completed by spring 1986.

**Manitoba's approach.** Manitoba sets its standards in terms of the impact certain chemicals (for example, ammonia) in the effluents have on the receiving stream, but not for BOD because of the difficulty of enforcing it. The approach is favoured politically, even though technologically it may have its shortcomings.

**Ontario's approach.** Ontario's effluent requirements are fairly standard across the province, except for specific receiving waters. If a receiving water requires a higher quality effluent, the requirements are determined through receiving water assimilation studies. The sewage treatment plant at Milton, although not a lagoon, is nevertheless an example of special effluent quality requirements:

BOD: 4.2 mg/L

| | |
|---|---|
| Phosphorus: | 0.43 mg/L |
| Ammonia: | 90% removal (in summer; winter is of no concern) |
| Residual chlorine: | 0.08 mg/L |

Ontario's requirement under the Canada/U.S. agreement is 1 mg/L of total phosphorus in the effluent. (We do not distinguish between total phosphorus and soluble phosphorus.) Where phosphorus cannot be discharged during the summer, sewage is treated in seasonal retention lagoons. Some special requirements for phosphorus in discharges:

| | |
|---|---|
| discharge into Lake Simcoe | 0.3 mg/L |
| summer discharge at Stratford | 0.1 mg/L |

**Consultants' point of view.** Regulations largely govern what design is required in various regions of Canada. The Territories, through their water boards, consider the capacity for dilution in the receiving stream and hence vary the effluent quality requirements from location to location.

Provinces, such as Alberta, use standard effluent quality criteria which are easier to regulate, while ensuring high-quality effluents. Too great an economic burden may be imposed on some communities in Alberta by regulations insisting on a pond for long storage which may not be necessary where a stream offers dilution and assimilation capacities.

3.1.3 **Wastewater Characteristics.** When dealing with a process - here the process of wastewater treatment - we must be concerned with what goes into the process. And the degree to which wastewater is diluted, a characterisic of the wastewater, becomes a very important consideration in hydraulic designs.

The degree of wastewater dilution matters to the ranges of many parameters; e.g., the greater the dilution, the greater the range of fecal coliform. From the point of view of hydraulic design, the degree of wastewater dilution affects the organic or fecal coliform or solid loading (see Table 2).

The practice of bleeding the water lines to prevent freeze-up is basically town-specific. It results in sewage as weak as 50 mg/L BOD and suspended solids. Using water simply to keep water lines from freezing is very expensive in the North.

In Whitehorse, water use is high: 440 L/p·d partly because of water bleeding, partly because of very high infiltration into the sewage system.

| Degrees of Dilution of Lagoon Influents | Occurrence |
|---|---|
| undiluted | Many Indian Reserves and small northern communities, where human wastes often enter the lagoon directly or are delivered there by pump-out truck |
| moderately diluted | Work camps or places practicing water conservation |
| conventionally diluted | Municipalities with normal water use and tight severs |
| greatly diluted | Unique to intermediate regions of Canada;<br>Causes:<br>• water bleeding (to keep water supply pipes from freezing up),<br>• failures of collection system,<br>• excessive infiltration because of submergence of the collection systems. |

When considering the use of a sewage lagoon system, the design engineer should look at infiltration rates and water bleeding rates. The size of the pipes need to be adapted to the wastewater flow.

Municipal lagoon systems may receive industrial wastes which can affect treatment efficiency and odour generation.

TABLE 2 RAW WASTEWATER CHARACTERISTICS (reported by Ron Kent)

| Community | Flow Ratio* | BOD (mg/L) | SS (mg/L) | Total Coliforms (per 100 ml) |
|---|---|---|---|---|
| Small, using honey bags | 0.5 | 300 | 360 | |
| Norman Wells | 1.2 | | | $<1 \times 10^6$ |
| Yellowknife (actual**) | | | | $1\text{-}96 \times 10^6$ |
| Inuvik (projected) | 1.2 | 250 | 250 | $8 \times 10^6$ |
| (actual**) | | 110 | | $21 \times 10^6$ |
| Fort Smith | 1.5 | 200 | 200 | $7 \times 10^6$ |
| Whitehorse projected | 4.4 | 70 | 70 | $2 \times 10^6$ |
| actual | | <70 | <70 | $4 \times 10^6$ |

* Flow ratio of 1.0 is equivalent to 300 L/p•d (an assumed average value).

** The high total coliform counts in the Northwest Territories cannot be adequately explained, other than that a different method of counting coliforms is used.

**3.1.4 Sludge Buildup.** U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory Special Report 84-8, April 1984, "Accumulation Characterization and Stabilization of Sludges for Cold Regions Lagoons" suggests accumulation rates in the range of 0.25 $m^3$ of sludge per day per 1000 persons. The reason for this type of a range is that it appears that the lower the mean annual temperature of the lagoon contents the more sludge accumulated per capita. Some information suggests that a lagoon located in the southern U.S.A. will have much less sludge accumulation; whereas in places such as the Northwest Territories, the 0.25 $m^3$ may be an underestimate of the amount of sludge being accumulated.

The Whitehorse lagoon, which has been in use for 6 years, was just sampled and a rate of .77 g/p•d was found. It is about double the rate quoted in literature. It is also full of motor oil, which does not help our toxicity situation. It may be that we have a bulkier sludge because the lagoons are very deep and very cold.

In municipal facilities, there is no demonstrated need for sludge removal in 10 or 15 years of operation, for example. That relates to some extent to the amount of anaerobic digestion that goes on. In Southern Ontario where lagoons operate during extended periods of warm temperatures and shorter periods of cold temperatures the sludge undergoes anaerobic decomposition and compaction. Perhaps in a more northern situation we would not see that anaerobic decomposition and consolidation of the sludge and because of that would probably accumulate sludge at a significantly higher rate.

Last fall, we measured the sludge in aerated lagoons. We arrived at the accumulation rate of about 0.17 $m^3$/d 1000 people equivalent.

Sixteen years after the Winnipeg cells went into operation, the most we found was 0.3 m of sludge right at the outlet pipe. In some places there was absolutely no buildup.

Alberta experience shows that for its lagoon configuration of anaerobic cells ahead of facultative treatment cells that the sludge in the anaerobic cells must be removed two or three times during their design life.

No problems were reported with sludge removal from the treatment or storage ponds.

## 3.2 The Environment and Public Health

The protection of the flora and fauna of the receiving environment and the maintenace of an aesthetically pleasing environment are among the objectives for wastewater treatment. Treated wastewaters are discharged to the environment to be diluted and further purified by natural processes to convert them eventually into a usable source of water.

This section considers lagoon effluent quality and alternative disposal options from the environmental perspective, but its main thrust is on the public health aspects of lagoon operation. When all is said and done about BOD, suspended solids, and other environmental factors, the key issue is disease prevention and aesthetics:

- how to gauge the cleaniness of the water relative to the number and kind of pathogens present,
- how to deal with pathogens that have developed a resistance to antibiotics, and hence have an increased survival rate, and
- how to curtail their distribution through aerosols and foodstuffs, particularly mussels.

We are not only concerned about water for consumption (drinking and food preparation) but also about water for recreational use.

The concern for public health implies concern for public safety for people living, working, and playing near lagoons. For example, all areas of land used in wastewater treatment or waste disposal should be fenced off and identified with warning signs.

Particularly in the North, there is generally plenty of assimilative capacity available for sewage effluent in receiving bodies. So it is the public health concern, the protection of shorelines and water for recreational uses, that must be emphasized.

**3.2.1** **Impact of Lagoons on the Environment.** Several options for effluent disposal depend on site-specific conditions.

In the summer, most of the receiving waters, whether rivers or lakes, have a fairly high assimilative capacity. The indicator organisms have a relatively short survival time because of the intense solar radiation. Reaeration of the system is usually fairly rapid, and therefore moderate amounts of organic material can be assimilated by the stream.

In the winter, the volume of the receiving waters is low, because:

- assimilative capacity is greatly reduced;
- survival of indicator organisms is extremely long, whether in the lagoon or in the river;
- reaeration has stopped; and
- microbial metabolism consumes oxygen which can cause problems in smaller rivers.

**Groundwater recharges.** The nitrate concentrations in wastewater are high, at least during the summer period. To prevent the nitrate from entering the groundwater, the wastewater has to pass through an anaerobic zone for denitrification.

**Wetlands discharge.** Wetlands discharge may be a suitable alternative. Land discharge has been used at several locations in the Northwest Territories and elsewhere in Canada. This method is discussed in some detail in Section 3.4.2.

**Spray irrigation.** Lagoon systems with their built-in storage capacity lend themselves to effluent spray irrigation where the systems are adjacent to fields or woods.

**3.2.2 Public Health Concerns.** We have to get back to the basic purpose for the wastewater treatment system and that is the protection of public health. Public health aspects need to be addressed first, particularly for sewage lagoons located in areas of northern Canada.

We have much to learn about cold-climate environmental microbiology and the effect of microbial activity on humans. Several enteric pathogens are not properly represented by the fecal coliform group as an indicator of pollution. This could become a serious problem within the next 10 years, if people continue to use their water resources for more than transportation and disposal of waste without due regard for consequences to the public health.

**Bacteria/viruses: the main concern in the Territories.** The basic purpose of a wastewater treatment system is the protection of public health. Therefore when dealing with lagoon systems, issues concerning public health must take priority. North of the 60th parallel, there is more concern about bacteria and viruses than about BOD, suspended solids, and nutrients. Viruses, such as polio, survive three times longer than E. coli and streptococci. Viruses are found in lagoon effluents regularly.

Assimilative capacity is available; very cold temperatures prevail: tremendous oxygen sag curves below the outfalls do not occur.

At spring breakup, when most of the lagoons are discharged, the water is too muddy and too full of ice to serve as drinking water.

With continuous discharge locations, such as Fort Smith, bacteriological quality is more important than the chemical quality of the effluent.

**R-factor.** During testing conducted in Edmonton by the University of Alberta about 24 percent of the fecal coliforms being discharged from the treatment system were found to be mutants: they carry an extra plasmid in their cell. This mutation imparts resistance (R-factor) to certain antibiotics on these bacteria.

Of these mutants, 3 percent can transfer this drug resistance to other organisms. Many outbreaks of disease in the last few years have been attributed to bacteria carrying the R-factor, particularly Shigella and Salmonella.

The data that have been collected so far suggest that fecal coliforms having the resistance to drugs live longer than those not having that resistance regardless of the type of wastewater treatment system. In fact, this phenomenon is even more marked with fecal coliforms in long-retention lagoons than with coliforms in conventional treatment systems. No increase in R-factor has been found in raw sewage. When studying the reduction of pathogenic organisms in lagoon systems, we must also make sure that the organisms with the R-factor are reduced as well.

Many of the fecal coliforms are resistant to many of the antibiotics and to several of the commonly used disinfectants - chlorine and ultra-violet light in particular.

**Mussels.** Mussels and other shellfish including crabs accumulate a bacterial population - including coliforms and other pathogens - in their tissue to a concentration 40 times that of the surrounding water. Where the community beach plays a role in food collection (mussels) and food preparation (cleaning whales, seals, and fish), and where for reasons of topography the effluent discharge point in near that beach, the effluent should have a bacterial count no higher than that acceptable for drinking water at discharge or even before discharge.

**Aerosols.** Bacteria and other organisms can be spread by aerosols. Legionella disease is now considered to be spread through aerosols produced, for example, by a shower head. The spread of Legionella through aerated systems should be investigated. This aspect should be included in any research being done on aerated lagoons. Even if it does not affect the operators, it could be transmitted to their families or to people in the vicinity of lagoons who might just pick it up from a downwind spread.

- The aerosols associated with high-rate biological systems will likely be more serious than those associated with lagoon systems. In addressing the aerosol problem, the activated sludge process and other high-intensity aeration systems should be studied first. (Aerosol studies on wastewater systems in the U.S.A. have shown little or no adverse health effects on system operators or on the population living near the wastewater systems.
- In Edmonton, aerosols have been monitored around the plant, and indicator organisms have been found moving all over the river valley.

- A recent study on the lagoon at Roblin, Manitoba, included some monitoring of the aerosols around the spray irrigation effluent land disposal system.

**3.2.3 Honey Bags as Means of Waste Disposal.** Over the last 5 years, more and more plumbing has been installed in houses in the North to improve waste disposal. This has been part of an effort to upgrade the housing standards within some communities where honey bags were used extensively. Once that upgrading has been completed, pump-out sewage and water truck delivery will become the minimum standard.

The use of honey bags as a means of disposing of human waste is so widespread that their replacement cannot be foreseen for another 30 or 40 years, although various alternatives have been evaluated. Users tend to resist efforts to replace them by some other system. In the meantime, one possible avenue open for improving waste disposal by honey bags is to make them of a degradable material rather than plastic. Until honey bags made of degradable material exist, they must not be dumped into lagoons. There is a need for a practical system to permit disposal of honey bags into lagoons.

**3.2.4 Validity of Standard Test Methods As Related To Suspended Solids in Sewage Lagoon Systems.** Regulatory agencies fail to differentiate on the form of the suspended solids and their significance on the environment. An algal cell ready for something to eat is something different than raw sewage solids going out of the system. For lagoon effluents the composition of the solids varies from season to season mainly as the algal cell concentration varies.

Not justified either may be the aim to achieve the same suspended solids level - between 25 and 35 mg/L - for different receiving waters. It should not be assumed that the same suspended solids level is as valid for the estuary of a river as it is for any other stretch along that same river.

"If you discharge to the Fraser River at 100 m upstream from the mouth rather than in some region in the middle of northern Alberta, I suspect the requirements of the receiving water are very different and yet we seem to have the same magic number for suspended solids - usually between 25 and 35 mg/L", says Ross Bulley.

Also, BOD measurements should take algal cells into account. For example, if lagoon effluent containing algal cells is put into a glass bottle exposed to light, a negative BOD is measured. If, however, the bottle is incubated in the dark, the effluent not only reflects the organic degradation meant to be measured, but also the respiration of the algae present. Filtered BODs are another common practice of trying to get away from that problem, but if suspended solids other than algae are filtered out, then the reading is not accurate either. This is a problem still awaiting a solution.

Even when we talk about the influent BOD, we very rarely talk about the ratio between the soluble BOD and the total BOD. "There are so many unknowns."

**Testing for total dissolved solids rather than BOD.** Advantages of testing for total dissolved solids:

- is faster;
- has none of the problems posed by BOD at low concentrations;
- can be correlated with BOD; and
- yields reproducible information.

Advantages of testing for BOD: it is the best test available for understanding the biodegradability of material.

Neither may provide a good parameter for testing the performance of a wastewater treatment system.

"Once data packages have been assembled from a very extensive backlog of existing data, we can determine better which parameter to monitor. With the amount of automated control in mechanical systems, the BOD cannot be used as a parameter because of the long time lag involved," says B. Jank.

**Validity of fecal coliforms as indicator organisms.** We need confirmation that the presence and number of fecal coliforms bear a relation to the presence and number of pathogenic bacteria. Perhaps the fecal coliforms have changed and are no longer the same as those for which the standards were developed 30 years ago. We need to know whether or not the fecal coliform test applies to organisms living in a lagoon environment.

That's just one issue. Another issue is protozoan parasites such as Giardia lamblia which are becoming endemic throughout North America. These organisms are not represented by fecal coliforms any more than viruses are. We know that relatively few viruses or protozoan cysts, whether it be Giardia lamblia or Entamoeba histolytica may be enough to cause infection, particularly in an unhealthy individual.

**Effluent toxicity testing.** The toxicity of effluents to fish, wildlife, animals and humans must not be overlooked. There is, therefore, a need also for appropriate bioassay test procedures. Problems of effluent toxicity caused by ammonia and hydrogen sulphide are discussed in Section 3.4.1.

This is a challenge in Whitehorse, Y.T., where the effluents have to comply with the Fisheries Act, i.e., they must not be toxic. Yet the effluents from two anaerobic lagoons are toxic.

### 3.3 Operation and Process Control

People's perceptions of what is required to operate and maintain a lagoon system vary widely from installation to installation even under the same regulatory agency. Some people would not go there more than three time a year, resulting in extremely low operating costs; whereas others visit a lagoon site twice a day because they feel that is necessary.

The first objective for the operation of a lagoon system is to produce a high quality effluent, whether that be from the environmental point of view or from that of public health. The second is to keep records for an information base for future use whether for expansion of the system or for alteration of design procedures. (Had our lagoon installations been monitored adequately in the past, we would have most of the information we now need). The third objective is to prevent mechanical/structural failure in the system. Such failure is one of the biggest problems in trying to operate a lagoon system. To achieve this objective, it is essential to have a trained, knowledgeable, and dedicated operator.

**3.3.1 Lagoon Performance and its Monitoring.** In Ontario, lagoons were first built in the 1950s. In the early years of their use, the majority were operated with continuous discharge based on a design retention time of 120 days. When problems arose in the receiving waters for lack of dilution during the summer, many of them were converted to seasonal discharge, thus retaining the flow during summer and winter. Besides those discharging spring and fall, some discharge all winter and others only in the spring, depending on the available retention time. This experience and practice is commonly shared across Canada.

For example, in Manitoba where there is not always a flowing stream to discharge to, lagoon systems are operated for discharge during the most appropriate time of the year. "Most of the year it's either dry or frozen, so it's a matter of holding the effluent, treating it, and then discharging it during the most appropriate time of the year", according to Mike Van Den Bosch.

When discharging from a large lagoon into an intermittent stream, co-ordination is a potential problem of when to start discharge and when to stop it. This is particularly so if the hydraulics of the system do not permit discharge at the desired rate of flow; i.e., there is not enough static head available to overcome friction losses. The example given during the workshop was that of a 16-hr lagoon that took about a month to discharge because the effluent pipe was too small for the available static head.

Some means of measuring the sewage flow to the lagoon should be found. At many lagoon systems this is done at the raw-sewage pumping station. The calibration of the measuring device should be checked monthly. Samples of the influent and effluent should be taken monthly at continuous discharge systems and sent to a qualified laboratory for analysis. For seasonal discharge lagoons, sampling should start about 1 month before discharge.

An indication of good effluent quality is good light penetration into the lagoon. The operator can also learn to gauge lagoon performance by the number and variety of organisms in the water and the plants growing on the bottom and sides. Much is still to be learned about these indicators of lagoon performance. Are duckweed and cattails indicators of good water quality when they are found only at the effluent end of the system? Are other plants only found under anaerobic or faultative conditions? Plant varieties, as well as algal species, daphnia, and other insects need to be watched for their signs.

Sludge accumulation should be checked every 3 months to provide some data with which to judge removal requirements later on. Sludge depth may be measured by establishing the bottom elevation relative to a benchmark outside the pond, such as the top of an overflow chamber or a concrete structure. Once the top of the concrete and the bottom elevation are known, then the operator can go in and probe with a pole to which big plate has been attached, to feel the sludge layer. The elevation is referenced to the water surface and to the benchmark. Then the accumulated amount of sludge can be calculated.

Also, a device called a 'fish ray', which is an electronic hand-held sounder, yields a good reading (accuracy: ± 0.3 m) of the depth of soft sludge by echo.

**3.3.2 Record-keeping.** Every lagoon operator should use a log book to record all his activities. He should not hope to remember events and actions 1 month from now and certainly not 4 and 5 years later. He needs to record:

- when the ice cover disappears,
- what the dissolved oxygen levels are under the ice,
- when odours occur,
- depth and location of the bottom sludge,

and much more regarding the condition of both the lagoon contents and its structures. With good records the operator may, for example, establish whether there is a correlation between sludge depth and objectionable odours when the ice melts.

At some lagoons, odour problems do not occur until after the water temperature started to warm up and biological activity increases in the sludge layer. That happens probably 4 to 6 weeks after the ice has disappeared. Unless such information is recorded regularly basis, two or three times a week, we cannot really arrive at any conclusion.

More things to be checked and recorded:

- the flow distribution in multi-celled systems,
- liquid level,
- colour of the lagoon contents,
- presence of odour,
- presence of ice cover,
- structural integrity of the system,
- removal of step logs from flow control chambers,
- improperly turned control valves,
- occasions of vandalism, and
- condition of warning signs.

3.3.3 **Maintenance.** Maintenance activities must also be done regularly or as required:

- clearing the access road,
- clearing the access to flow distribution chambers and valves,
- checking the shoreline - vegetation and erosion (monthly),
- grass cutting (monthly),
- testing valve operability (monthly),
- removing snow and ice, particularly around the inlet and outlet areas,
- mending exterior fences, and
- controlling animal and insect influx.

For lagoons in permafrost areas, operators should also be monitoring berms to ensure that they are functioning as desired; they need to watch for icings that may occur on the downstream slopes as a result of leakage and seepage leading ultimately to piping-through due to the thermal problems. In addition to these visual examinations it may be advisable to install ground temperature cables and movement monitors so that the safety and integrity of the structure can be determined more accurately.

Removal and disposal of sludge as part of lagoon operation and maintenance is yet to be adequately addressed. With multiple cells, one cell can be drained to allow the sludge to freeze in the winter and dry out in the ensuing summer. The relatively inoffensive product can be hauled away to a sanitary landfill site or used as a fertilizer after coarse screening.

A number of provincial jurisdictions now have standards or guidelines for the deposition of sludge on agricultural lands.

**3.3.4 Operator Training.** We spend a lot of money to build our sewage lagoon systems. If we don't maintain them, we are wasting this investment. So operator training is very important.

Very often the operator has not been told what to do to operate and maintain his treatment facility properly. Knowledgeable operators have the greater appreciation of the system they are dealing with, and therefore the process is going to work better. Even a 1-day workshop on lagoons will help to familiarize operators with their job functions. Good operators, who know what they are doing, can make a badly designed system produce an effluent of fairly good quality. Even an excellently designed system requires a trained operator to maintain it and to produce a good quality effluent.

Training gives an incentive to operators to improve their knowledge on lagoon operation and maintenance procedures. See Appendix D-5.

The training program should stress the importance of monitoring the system and maintaining good records. It is difficult to convince operators that this is important. They are very reluctant to maintain such log books.

It helps learning to organize training sessions where a number of operators are together. They all benefit from the resulting interaction - the sharing of problems and solutions from their own experiences. A selection of good training material is available for different skill levels on the subject of sewage lagoon operation and maintenance upon which to base training sessions.

In Northern Quebec, communities are very closely knit; there are a lot of interactions between them. For example, the Catholic School Board has set up a training centre in a central municipality to give specialized technical courses to the 13 other municipalities in the region. This brings people from different municipalities and backgrounds together and allows friendships to develop during the learning process, creating a brotherhood of operators in a certain region, reinforces motivation and the care which the operators put into their jobs. For some, these human considerations may appear to be a waste of time, but experience in training Inuit and non-Inuit people indicates that when a student feels isolated on the job, no benefits are derived from the training sessions. This is especially true for training concerned with wastewater treatment plants.

For native operators the language of the course should be the native language. The teacher may give the course to the translator first so that the translator may have an opportunity to check the technical words or the unusual words. The classroom material should also be in the native language.

The training centre should be near the operators' home. It is always difficult for most people to be away from home for any extended period of time. If on top of that the trainees, especially natives, are subjected to the distractions of a foreign environment they will rapidly lose interest and ask to go back home. So the place of training is very important for the operator trainees.

The course given in Quebec is quite long.

The total hours required for operators in Quebec is 360 hours. So that's about a 9-week period at 40 hours a week. This is quite extensive but necessary.

Longer courses mean more knowledge for operators. They will be more self-sufficient, more able to identify real problems, and more prepared for dealing with them. Two hundred and twenty-five hours of the program are devoted to what the job is, how to read plans and specifications, mathematics, general science, the metric system, basic electricity, domestic wastewater characteristics, sewage systems, and wastewater pumping stations. The most important part of the training is not the sewage lagoons themselves but all these prerequisites.

The content of training programs in Canada or at least in a given province or territory should be standardized and not left to local authorities. This way the ultimate goal of achieving operating efficiency and good-quality effluents across the country could really be achieved.

The training period could be broken down into meaningful segments. Where possible, the initial training session should coincide with the lagoon construction period. The trainee could then get breaks between the classroom and on-site instruction. To hold a training session as the lagoon is being built is very important so that the trainee has an opportunity to get acquainted with the system he or she is to operate.

In most northern communities the trainees should be the water truck and the wastewater truck drivers. It is desirable that the trainees already be municipal employees, used to dealing with wastewater, and be from the group that has the lowest personnel turnover rate.

### 3.4 Upgrading the Performance of Existing Lagoons

Basically lagoons may be upgraded to increase capacity and to meet more stringent requirements for other parameters. In Ontario, for example, lagoons have been regulated for:

- nutrient removal to avoid eutrophication,
- BOD reduction in the effluent or the receiving water,
- toxicity reduction,
- bacteria removal, and
- odour prevention and control.

#### 3.4.1 Overview of the Ontario Experience

**Nutrient removal.** Phosphorus removal was one of the first topics addressed in the upgrading of lagoon systems. The policy on phosphorus removal, begun in 1970, applied to the lower Great Lakes, the Muskoka/Haliburton cottage area, and the Ottawa-Carleton region. It covered all sewage treatment facilities whether mechanical or lagoon types. A major program of jar testing, treatability studies, and full-scale demonstrations was undertaken involving chemical addition with alum or ferric chloride.

For continuous discharge lagoons without electrical power at the site, the chemical is metered into the forcemain from a storage facility at the main pumping station or into a main hole of the gravity sewer to the lagoon. Generally alum is added to achieve a concentration of about 150 mg/L. Jar tests are carried out on every system to determine the required dosage. Approximate alum-to-phosphorus ratios are not used.

Jar tests are also carried out before the batch dosing of seasonal discharge lagoons. In Ontario, where batch treatment has been praticed for at least 10 years, the dosage is down to about 80 mg/L of aluminium sulphate.

For seasonal retention lagoons, batch addition is carried out from a boat equipped with chemical storage tanks. The chemical is metered out into the wash area of the propeller. After the allotted quantity has been dispensed by running the boat around the lagoon, a second boat is used to mix the chemical further.

For continuous-discharge lagoons, the 1 mg of phosphorus/L requirement is achieved quite readily.

For seasonal retention lagoons, excellent effluent quality is achieved:

| Component Removed | Range (mg/L) |
|---|---|
| BOD | 15 - 20 |
| Suspended solids | 5 - 10 |
| Phosphorus | <1 |

There are two limitations in batch-treating these lagoons:

- the ice cover must have disappeared, and
- discharge has to occur over 10 to 14 days; faster discharge may result in deteriorated effluent quality with regard to BOD and suspended solids because of turbulence.

**Reduction oxygen demand and bacteria.** The lagoon system at New Hamburg, Ontario, consisting of two facultative cells in series, was causing problems with dissolved oxygen depletion, ammonia, and hydrogen sulphide in the receiving water.

Trial Test Filter. A shallow, effluent rapid sand filter was installed for a trial and operated in two different modes over 16 months. During the summer the filter was operated in an intermittent mode to produce the results shown in Table 3. The filter removed BOD, suspended solids, phosphorus, and ammonia really well.

In the winter, to eliminate freezing problems within the filter bed, the filter was flooded from November to March. The filter still achieved good BOD and suspended solids removals; but the phosphorus level in the effluent was quite high, and no ammonia was removed at all.

Full-Scale Modifications. An aeration cell with chemical feeding facilities for phosphorus removal was built ahead of the existing cells. Four effluent sand filters were built after them. The lagoon effluent is run through the filters only during the summer period at a loading rate of 600 L/m$^2$·d intermittently. The surface of the filters has to be raked periodically to maintain the desired flow. At that rate, the facultative cells are empty enough to provide complete storage over the winter months.

The effluent sand filters are also an effective means of reducing the number of bacteria being discharged in the effluent from lagoon systems.

**Toxicity reduction.** At Markdale, Ontario, the continuous discharge lagoon caused problems with eutrophication and ammonia toxicity in a pristine trout stream. The soil in the area is very coarse. The ground slopes steeply from the lagoon to the receiving stream. It was a good place to add a rapid exfiltration cell.

A test cell was operated on an intermittent feed basis for 18 months. From this experience a full-scale facility consisting of eight different exfiltration cells was built. Also an aeration cell was added ahead of the original lagoon. Chemicals for phosphorus removal are added now also ahead of the system.

Four of the cells are fed at a time for a week (Week 1). They are then allowed to stand for the next week (Week 2). Meanwhile during Week 2 the other four cells are fed at a rate of about 1200 $L/m^2 \cdot d$. The cells are operated alternately in this manner for about 240 days. The sewage is stored in the lagoon over the winter months for the rest of the time.

Results. From test holes:

- phosphorus with an initial concentration of 1 mg/L moves about 50 m through the soil,
- ammonia undergoes complete nitrification/denitrification in about 60 or 80 m.

The underground flow emerges on the surface and flows through a marshy area before reaching the stream.

The system has been in operation since 1981 and already improvement in the receiving stream is noticeable.

At Sutton, Ontario, an extended-aeration plant with an earthen, complete-mix cell followed by a mechanical clarifier and seasonal discharge lagoon within the aeration caused problems with ammonia and hydrogen sulphide in the effluent.

Control Strategy. The operation was modified to achieve a sludge age of about 30 days during the summer and 60 days during the winter. Chemicals for phosphorus removal are added to the influent of the clarifier. All the waste activated sludge is discharged into the effluent launder of the clarifier from where it goes into the lagoon. Once in the lagoon, the sludge is highly degraded because of its extremely high sludge age. All winter long, high nitrate concentrations are discharged into the lagoon, keeping the contents from becoming anoxic.

TABLE 3 DATA FROM UPGRADED ONTARIO LAGOON SYSTEMS (mg/L)

| Place | Source | BOD | Suspended Solids | Total P | $NH_3$ |
|---|---|---|---|---|---|
| Thornbury | Influent | 332 | 137 | 3 | - |
| | Effluent* | 7.5 | 13 | 1 | 4 |
| Sutton* | Influent | 148 | 208 | 6 | 19 |
| | Secondary effluent | 8 | 13 | 0.9 | 0.3 |
| | Lagoon effluent | 6 | 11 | 0.4 | 0.6 |
| New | Influent | 137 | 193 | 6.8 | - |
| Hamburg | Effluent | 1 | 5 | 0.8 | 2 |

* No measureable hydrogen sulphide found

Results.

1. full nitrification both summer and winter,
2. high levels of phosphorus removal,
3. nitrogen removal through denitrification,
4. hydrogen sulphide control, and
5. negligible sludge buildup.

**Hydrogen sulphide odour control.** The lagoon system at Thornbury, Ontario, treating municipal wastes with a major component from an apple-processing plant, caused severe odour problems at the time of spring discharge. The facility consisted of a pre-aeration cell followed in series by two secondary cells.

The Ministry of the Environment looked for a means of controlling the hydrogen sulphide odour resulting from the overloading caused by the high-strength (soluble BOD) apple-processing wastewaters.

Following a number of pilot-scale tests, static-tube aerators were installed throughout the two secondary cells. The aeration equipment was designed to provide 2.2 kg of oxygen per kg of BOD in the effluent from the pre-aeration cell. The static-tube aerators are operated only during the winter. The low level of aeration provided keeps the ice from forming above the aerators and results in very effective hydrogen sulphide control.

3.4.2 **Natural Wetlands Treatment.** Natural wetlands treatment has a significant potential for the removal of BOD, suspended solids, bacteria, and nutrients at low cost in a number of location in northern Canada.

**Saskatchewan.** Indian Reserves in Saskatchewan are a good example. Saskatchewan is generally a very heavy user of sewage lagoon technology. About 90 percent of the Province's wastewater treatment systems are sewage lagoons. Saskatchewan has all these lagoons because land is plentiful, inexpensive, and flat. But on Indian Reserves the land is not always flat, instead it tends to be swampy, muskegy, sloughy, and of varied strata.

In 1984, Indian and Northern Affairs Canada commissioned the University of Regina to undertake a microbiological assessment of four of its waste treatment systems to substantiate the case for the use of wetlands treatment systems. (Regina Water Research Institute, University of Regina, RWRI Report No. 30.)

**Northwest Territories.** Recently, Pine Point installed a wetlands treatment system as a solution to problems with an existing lagoon. That lagoon was re-oriented and cleaned up. Its effluent undergoes wetlands treatment with satisfactory results.

Another installation at Hay River treats wastewater in anaerobic cells and then discharges the effluent to 48.6 ha of bermed wetlands at a loading rate of 2.5 kg/ha•d. The system is maintaining good effluent characteristics. The effluent contains no phenols or hydrogen sulphide. In fact, the quality of the effluent from this system cannot be distinguished from the quality of water from a control creek outside the drainage area.

**Ontario.** Ontario has been studying the use of artificial wetlands systems. After 4 years of testing at the Listowel artificial marshland, a full-scale facility was built at the site of the Port Perry lagoon. Some problems in design and operation have been encountered, primarily concerning the presence of ammonia, phenols, and hydrogen sulphide.

In northern Ontario, an artificial marshland system preceded by an aerated facultative cell for BOD removal and chemical treatment of phosphorus is expected to achieve final effluent quality equivalent to secondary and tertiary treatment; i.e.,

| | |
|---|---|
| BOD | 10 mg/L |
| Suspended solids | 10 mg/L |
| Phosphorus | 0.2 to 0.3 mg/L |
| Ammonia | 4 to 6 mg/L |

However, the artificial wetlands system may be suitable in Southern Ontario, where a continuous summer discharge is desired.

**Northern Quebec.** Montreal's École Polytechnique conducted a 4-year, full-scale study at Fontage, near James Bay, into the use of peat bog wetlands for wastewater treatment.

Four peat bogs in a natural wetland were used in series to treat septic tank effluents. Good removals of suspended solids and BOD were achieved. The phosphorus was retained during the summer but reappeared later, especially during the spring runoff after having been temporarily absorbed by the peat fibres. The ammonia went through a series of nitrification-denitrification cycles.

Two design criteria were developed based on surface application and peat volume. At the trial installation, an effluent of drinking-water quality was achieved after a 1-km flow through the bog.

**Summary.** Adequate documentation of the performance of natural wetland treatment is needed to establish design criteria so that the various regulatory bodies will approve of the use of natural wetlands treatment of wastewaters.

Enough engineering should be done along the perimeter of a natural wetland area to keep any extraneous flows from running into it so that the proper retention time can be maintained.

The manual, "Land Application of Treatment Municipal Wastewater and Sludge" (Environment Canada, EPS 6-EP-84-1, March 1984), contains a section on wetland systems (Section 7.3.3, pages 121-125).

### 3.4.3 Nutrient Removal by Duckweed.

The City of Duncan, B.C., has an aerated lagoon followed by a polishing pond. The polishing pond effluent is chlorinated before discharge to a salmon river. The flow in the river becomes quite low in the summer. The City has been required to lower the phosphorus and nitrogen levels in the effluent. The addition of alum is planned to meet the required phosphorus level. Dr. Ross Bulley of the University of British Columbia has been retained to recommend alternatives for nitrogen and phosphorus reduction. The cultivation of duckweed in the pond is one such alternative.

**Characteristics of duckweed:**

| | |
|---|---|
| Size of leaf surface: | 8 $mm^2$ |
| Reproduction: | vegetative |
| Habitat: | surface of water |
| Roots: | suspended in water |
| Length: | 5 to 50 mm |

These plants can populate a body of water so densely so that they form a mat-like cover which can be easily harvested. They are direct users of ammonia.

**Phosphorus/nitrogen uptake and duckweed production rates.** Literature suggests that 4.6 kg (dry wt.)/ha•d is a typical production level.

The product contains 0.8 percent phosphorus and 4.6 percent nitrogen. According to laboratory investigation, the phosphorus-nitrogen uptake varies with the concentration of duckweed in the medium (effluent). The uptake can rise to 3 percent phosphorus and 8 percent nitrogen, when they are in excess in the effluent.

The production rates on a sunny day are as high as 24.8 kg (dry wt.)/ha•d. To obtain such high production rates, the duckweed has to be harvested every 3 or 4 days.

**Proposed trial study.** A trial installation for the lagoon at Duncan is being proposed. Harvested duckweed would be stored on-site for future studies into its use as animal feed.

The Duncan study would give phosphorus and nitrogen removal data, insight into harvesting requirements, and uses for duckweed, especially in the area of animal feed. The ecosystem itself would also be monitored, including its natural disinfection ability.

What is really being considered is a whole modification of the lagoon ecosystem. In the U.S.A. along with the planting of duckweed, investigators have been looking at the use of a new plastic product of vertical strips called "bioweb", a surface material that can be anchored to the bottom. It floats vertically standing up and undulating in the water. This provides a surface on which the bacteria and protozoa can attach themselves instead of settling to the lagoon bottom. All biological grazers present can harvest the bacteria. Preliminary results using both the aquatic plants and "bioweb" reportedly indicate 0.5 to 0.1 mg/L total phosphate and 3 to 20 mg/L ammonia removal per day of retention time.

3.4.4 **Harvesting Biological Production.** Microstrainers with previously unavailable fine fabrics as small as 5 microns are now being evaluated in the U.S.A. as effluent polishing equipment. The micro-strainers used for years in water supply systems to remove unwanted algae are in the order of 20 microns. Reasonable flow-through rates with relatively trouble-free operation have been reported.

This adds another possible dimension to harvesting by using such equipment on an internal basis whereby the total lagoon contents are filtered over a prescribed period of time. In this way, biological production would be harvested on a continuous basis. Because no chemicals are added, the product could be used for fish culturing or animal feed production. Such an approach would increase capital and operating costs. Perhaps the cost of harvesting could be offset by the savings in chemicals for phosphorus removal and other gains in treatment performance.

Information on fish culture in cold-climate sewage lagoons is sparse. Reference was made to a study done in Missouri where fish were grown in the first, second, and third cell of three paired cells. The other three cells were left as controls. The effluent quality from the cells containing the fish had improved over several years, relative to the controls.

An attempt was made in 1984 to raise pickerel (walleye) from newly hatched fry eggs to a fall fingerling in one cell of the Port Perry, Ontario, municipal lagoon. Something happened causing the loss of most of the fish population; however, those that did survive grew very rapidly. At first their weight doubled daily until the metabolic rate levelled off. At the end of the season the pickerel had a mean weight of about 25 grams.

Their diet, as determined from analyses of stomach contents, consisted of those species appropriate in size to the age of the fish, i.e., midge fly larva and daphnia.

Another piece of work was done by the Ministry of Natural Resources at a privately owned sewage lagoon near Parry Sound, Ontario. The second, third, and fourth cells, each about 0.4 ha in size, were planted with pickerel (walleye) eggs. They successfully produced 120 000 fingerlings for release in Georgian Bay which had been depleted of the species. They did not grow as well as the Port Perry survivors for want of adequate food resources. Because they were limited mainly to a diet of daphnia, their rate of growth slowed.

The University of Laval is studying the potential for production of useful invertebrate species, methods of harvesting, and beneficial uses derived from sewage lagoons and mechanical treatment plant effluents.

The sewage lagoons are very rich biological systems which offer opportunities to combine beneficial uses of plant and fish production with improvements in effluent quality.

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Some Unanswered Questions.

1. The economic potential of harvesting algae, aquatic plants and fish for animal feed, fish stocking, and other potential uses.

2. Information on the design and operation of practicable harvesting equipment and methods.

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## 3.5 Lagoon Theory

**3.5.1 Lagoon Limnology.** In the natural eutrophication process there is a progression from stable, environmental conditions where things happen slowly and productivity is generally low, through high productivity - not necessarily always the most desirable kind of production but still very high production - in which living organisms are reacting in response to the chemical and physical environment that can sustain the organisms that are adapted to it.

Beyond the eutrophic waters comes the unnatural situation called hypereutrophy, of which sewage lagoons are a good example. The relative stability of the neutral water is lost, and things happen extremely rapidly. Those of us who have spent much time around lagoons will recognize that one day it may be a brillant green from algae; and a week later, the water may be as clear as crystal and full of daphnia. Maybe the week after that, once the water clears up, rooted aquatic plants (duckweed) will show up. It is a continual turnover. These rapid changes are a response to enriched and changing environmental conditions.

Part of the reason for these rapid changes and catastrophic peaks and valleys of population are related to the unnatural lagoon environment. A polluted environment does not foster a full sequence of the normal predator-prey relationships to develop.

Some environmental conditions, such as sunlight and season of the year, we cannot control. During the wintertime everything slows down, although there are still other biological microcosms operating within the system.

Those things that do live under hypertrophic conditions have adapted to this particularly stressful environment, and because of limited competition can grow in large numbers.

Little is known of the factors that actually govern the process. Those studies that have been conducted have used the resources of the sanitary engineer in establishing loading in relation to anticipated effluent quality. Between these two, it is a black box with little known of the cause of actions and reactions. Until more is understood, it would appear that significant progress with design and effluent upgrading is unlikely to occur.

The lagoons of today have evolved to the point where they are the most common form of sewage treatment in Canada. In Ontario, they have been very successful in resolving the problems of wastewater treatment in the small municipalities since they were first installed in the late 1950s.

Great progress has been made in the last 15 years in terms of studying and understanding the actions and reactions that relate to nutrient input to water. For example significant progress has been made in controlling some of the unwanted effects of increased eutrophication on the Great Lakes. These same principles also apply to sewage lagoons.

The tools used by the limnologist can give insight into the black box.

Automated instrumentation is available for a large number of the water quality parameters which control the sequence of nutrient enrichment. We have measures of production and productivity. We have to differentiate between standing crop, which is an instantaneous measure, and productivity, which is an ongoing process. Often the standing crop in lagoons may not be all that large but the production is tremendous simply because there is a sequence of something being produced and something using it.

Another thing which should be regarded as important is modelling techniques. This is a very complex situation which some people such as Dr. Thirumurthi have devoted themselves to study. Modelling lets us sort out complex information to a rational understanding of what is taking place.

While the enlightenment of this black box may seem an ominous and time-consuming task, that need not be the case. In relation to the complexity of tackling Lake Erie or even some of the smaller lakes, it really is not as big a job as it would appear to be on the surface.

A very large backlog of data has accumulated. There is a very good understanding of the raw wastewater characteristics. The physical environment is a simple one: it is a system of fixed dimensions. If it's a standard municipal effluent, we can predict closely what its quality is going to be. The lagoon environment itself is enclosed; it is not divided by any physical barriers.

The environment is controllable: the apparent complexity is because of our past inability or lack of will to measure the (rapid) changes that are taking place. The solution is to use automatic, rapid sampling and analytical systems so that we can determine what parameters are changing. Then, hopefully, we can also determine these cause-and-effect relationships so that more control can be exercised over the system.

If the system can be understood, then once the system is understood practical methods of management can be developed. The objective should be to achieve a steady state of high production in the system rather than wild fluctuations of populations. If we had a steady-state situation, then we could undoubtedly produce an effluent that is as good as, or better than, any process that is currently available.

With mechanical sewage treatment the effluent is discharged at a stage where it is more readily suitable for the production of algae. In a lagoon system the effluent has gone through the algal stage and through the first level of secondary production where the autotrophic biological production has been consumed. Lagoon effluent, in fact, has passed through many steps beyond in the whole natural sequence of treatment.

The ultimate goal of all these treatment systems should be to produce something of value. If we can turn the pollution problem into a resource, then we have achieved the ultimate solution. The lagoon system has that option. The organisms that are being produced, the daphnia the mides and so on, are extremely important first food organisms for virtually all species of fish. If we can harness that productivity and turn it into something useful, then we have achieved what we have been looking for.

By understanding the population dynamics and what is going on in the lagoon, we could harvest and utilize the beneficial material that is being produced in this autotrophic system, whether it be at the algal or ot the daphnia stage. Theoretically, we could harvest almost all of the nutrients that are otherwise discharged to the receiving water and thereby return an effluent of a quality close to that of the receiving water. That's the direction in which we should be going.

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Question

If we are going to get into this harvesting business, aren't we going to drive the costs up to the point where another treatment process would be cheaper? We do not want to make lagoon systems into something so complex that they lose all the advantages that they currently have.

Response

At some stage we must be able to offset some of that cost by the value of the material removed.

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**3.5.2 Organisms in Wastewater.** Bacteria can be classified according to the minimum temperature at which they function. Mesophilic bacteria thrive in temperatures between 15 and 35°C, psychrophilic bacteria between 0 and 15°C. Bacteria that grow at 0°C are called psychrotophs. In winter, most lagoons are operating at temperatures favouring psychrophilic and psychrotrophic bacteria. At Inuvik, it was found that during winter about 80 percent of the bacterial population in a lagoon is psychrotrophic, only 1 percent during summer. The psychrophiles and psychrotrophs are thriving in the wintertime; but we do not know what percentage of the BOD they are removing, whether 5 percent or even 10 percent. In aerated lagoons, which operate at about 0°C, the psychrophiles perform very well in breaking down the organic matter in wastewater. It has been suggested that psychrophiles function better than mesophiles at low temperatures because they have a thinner cell wall through which they can acquire food more readily. Little is known about the nutrient requirements and the cell-yield coefficients of psychrophilic bacteria. We might assume that the phosphorus requirement is lower than that for mesophilic bacteria because of their slower reaction rates.

Effluent quality is a function of temperature. As the temperature falls, the rates of biochemical reactions decrease. Most of the rate coefficients used in equations for design models have yet to be defined for temperatures between 0 and 10°C. That is the range of temperatures where the bacterial population in a lagoon changes from mesophiles to psychrophiles and with a corresponding change in activity rates.

In the discharge of any treatment system are numerous viruses, bacteria, and protozoa. Protozoa, particularly of the genus Giardia, are becoming endemic throughout North America.

Different species predominate as the wastewater changes with time. The performance of a treatment process can actually be judged by the shifts in species distribution. Rotifers are one of the last organisms to take predominance, because they tend to eat protozoa as well as bacteria and algae. Very clean effluent predicates the presence of rotifers.

**3.5.3 Natural Disinfection Mechanisms.** A whole series of natural disinfection mechanisms occur in a lagoon system.

| | |
|---|---|
| Sedimentation: | The basic sedimentation process generally reduces the number of microorganisms by about 20 to 30 percent, perhaps even by 50 percent. This is very insignificant because we are dealing with total coliform concentrations in the order of $1 \times 10^8$/mL. The concentration of fecal coliforms in conventionally diluted raw sewage is $1 \times 10^3$/mL. |
| Sunlight: | Natural ultraviolet light reduces some microorganism populations. |

Adsorption: Organisms adsorb to other particles which may eventually settle out. For example, bacteria may adsorb to algae, and then the algae settle to the bottom carrying the bacteria with them.

Predatory Organisms: Not only protozoa and rotifers prey on bacteria but viruses, called phages, do so also.

Nutrient Deficiency: Nutrient deficiency for lagoons can mean lack of alkalinity or $CO_2$ availability.

Toxins: Periodically toxins are introduced to or released from a lagoon. Both ammonia and hydrogen sulphide can be toxic under certain conditions. Algae can be toxic to some pathogens. Or algae can produce a toxic environment in their immediate vicinity by giving off, over a short time, much oxygen.

**3.5.4 Effects of Temperature.** A sudden temperature drop in the fall destroys the algal population, at least that near the surface of the lagoon. The result is either a tremendous discharge of solids or the algae settle to the bottom to undergo anaerobic decomposition.

Where the temperature drop is gradual; i.e., where the temperature drops from about 20°C over a quarter or half a year, the microorganisms acclimatize to the cold environment. The microorganism then do not sustain the thermal shock that would normally kill them.

**3.5.5 Effects of Ice Cover.** Ice cover reduces the sunlight which in turn reduces algal growth and natural disinfection. The ice cover restricts $O_2/CO_2$ gas exchange at the surface of the lagoon. The thickness of the ice cover on lagoons varies from about 1 m in the central part of the country to about 2 or 3 m in the very northerly part. Snow cover reduces the amount of ice formation on the surface of a lagoon (snow is a good insulator), but prevents the penetration of any light into the water column. Ice formation greatly reduces, if not terminates, all algal activity.

**On freezing.**

- an aerobic facultative system becomes an anaerobic system within 1 or 2 days;
- little or no biological removal or organic material;
- little or no disinfection normally attributed to sunlight;
- BOD only reduced by about 25 to 45 percent, mainly by sedimentation but that depends on how much of the BOD is tied up in the solids about to settle.

Limited reduction in BOD is all that is happening, because the psychrophilic bacteria have yet to grow in number and start feeding on the waste. Therefore, for this period the raw wastewater is diluted by the lagoon contents, which are of better quality.

**During mid-winter.** The coldest water is at the ice-water interface; the warmer water (2.5 to 3°C) is at the bottom of the lagoon. Some anaerobic activity occurs very slowly: little of the soluble BOD is reduced.

Half-way through the winter, the dilution capacity of the lagoon has been reduced to such an extent that the effluent imposes undue stress on the receiving environment.

The effluent quality from the lagoon is no better than that from a primary treatment plant: approximately 30 percent BOD reduction and 60 percent suspended solids reduction.

Data, based on a lagoon in New Hampshire, reported by Middlebrooks, show that starting with October in one year till December the next year, the pattern just described is followed for BOD and suspended solids. The New Hampshire lagoon retained high fecal coliform concentrations all through the year, except in late summer.

**At spring breakup.** In early spring, the ice cover breaks up and as the upper layers warm up, lagoon inversion occurs, as well as:

- release of trapped gases: $H_2S$, methane, nitrogen, etc.,
- onset of algal growth, because of sunlight reaching water surface,
- increased biological activity, and
- aeration from the atmosphere.

Therefore effluent quality is substantially improved. This is why many of our standards now do not permit continuous discharge, at least through the harsh part of the winter. So we shut the lagoon off and wait until the quality of its contents has improved following spring breakup. The gases were formed anaerobically during the winter. Hydrogen sulphide is the major cause of foul odours from lagoons in the springtime. When organic loading does not exceed 22.4 kg BOD/ha•d, the problems with odour last for only 1 or 2 weeks during spring breakup - in the more temperate climate of the northern U.S.A. and southern areas of Canada. But organic loading is not the only determinant in the extent of the odour problem, the nature of the wastewater being treated matters too. Loadings, such as 22.4 kg/ha•d, that give good results with domestic wastes may be too high for certain organic/toxic industrial wastewaters, particularly those from food-processing plants.

Odour is mainly due to anaerobic decay. Anaerobes use sulphate as an electron acceptor and convert it to hydrogen sulphide. Odour can also be caused by organic acid formed during anaerobic decomposition - something that tends to happen more in the summer.

We can offer two potential solutions that may be considered for the prevention and control of foul odours from lagoons.

At mechanical sewage treatment plants, odour has been controlled by adding potassium nitrate to the wastewater. The anaerobes than use nitrate as the electron acceptor, thereby reducing the production of hydrogen sulphide, hence reducing the cause of foul odours. If potassium nitrate is to be added to lagoons, it would have to added directly or at the main pumping station.

Another method of reducing hydrogen sulphide release is the addition of lime to the wastewater in the lagoon during or just after ice breakup. Lime keeps the pH high, so that hydrogen sulphide reacts with it, forming calcium sulphide.

3.5.6 **Bottom Sediments.** The sediments at the bottom of a lagoon are a combination of inorganic and organic materials. Some of the $CO_2$, as well as some of the ammonia and nitrogen may be released to the atmosphere during certain parts of the year. The remaining organic matter and nutrients gradually leach into the water column. In the springtime, all of the leached material mixes throughout the water column to serve as a growth media for the microorganisms. Eventually it becomes necessary to remove the stored sediments to reduce the amount leaching into the water column.

### 3.5.7 Nitrogen Compounds

**Nitrification-denitrification.** During summer, with the weather being warm, nitrification occurs. In nitrification, ammonia is converted to nitrite and nitrate. Perhaps in climates such as those in southern Ontario, natural oxygen sources under the ice even allow some nitrification to occur during winter, although the rates would be very low. Nitrification through microbial metabolism above does not reduce the amount of nitrogen in the water column. Other microorganisms reduce the amount of nitrogen in the water column by denitrification. In that process the bacteria use nitrate and nitrite as a source of oxygen, and produce nitrogen gas. The nitrogen gas dissolves to saturation in the water column, and the surplus is released to the atmosphere or accumulated under the ice cover. If denitrification does not take place, then nitrogen can only be lost either by being tied up in the microbial cells or by settling to the bottom.

**Volatilization of ammonia.** With intense surface activity or with an increase of pH (to greater than 10) in the upper tens of millimeters of liquid, ammonia volatilizes to the atmosphere. Another ammonia removal mechanism is air-stripping. Air-stripping occurs when we have supersaturated oxygen conditions in a lagoon. In fact, some evidence points to air-stripping as being the principal means, rather than nitrification-denitrification, by which ammonia is removed from lagoons. In Ontario, small receiving streams show ammonia toxicity, particularly during spring discharge and following discharges from seasonal retention facilities. Furthermore, no analytical data have shown nitrate levels in lagoon effluents that were not directly related to some industrial nitrate input into the influent.

**3.5.8 Alkalinity Changes.** Aerobic respiration without the decomposition of nitrate results in no change in alkalinity of the liquid in the lagoon. But with both nitrification and denitrification a change in alkalinity does occur. During nitrification the alkalinity decreases because the hydrogen ions released in the process neutralize hydroxyl ions. With denitrification, however, hydrogen ions are taken up, hence an increase in alkalinity. Therefore, wastewater containing a high concentration of nitrogen compounds may cause, through nitrifying and denitrifying bacteria, a shift in pH. If the shift is toward a decrease in pH, the lagoon system may stop functioning properly. With a deficiency in alkalinity the concomitant deficiency in $CO_2$ results in a nutrient-limiting condition for the microorganisms.

**3.5.9 Dissolved Oxygen (DO) Levels.** Lagoons in southern Ontario maintain relatively high DO levels when ice forms until sometime in January and even February. The DO level does not drop to zero until late March/early April. The findings are based on numerous measurements taken with a membrane-type DO meter at municipal and industrial lagoons.

Two hypotheses can be formed to explain the high dissolved oxygen levels under ice cover:

1) the oxygen is present in the incoming sewage;
2) sunlight reaches algae through a clear ice cover, so that the algae can photosynthesize.

The second hypotheses hold the greater promise. Unlike lagoons in the Arctic, those in southern Ontario are not continuously under snow cover. To find algae growing during most of the winter is common. Systems that have continuous discharge during winter provide very good BOD reduction.

**3.5.10 Psychrotrophic Bacteria.** There have been some studies of psychrotrophic microorganisms, which by definition grow at 0°C. Psychrotrophs work better at the lower temperatures seemingly because their cell walls are quite a bit thinner so that certain types of materials penetrate more easily and as a result they are able to acquire food much faster at low temperatures than mesophiles can. But one misconception has been that perhaps the psychrotrophs will be able to work as fast as the mesophiles. In other words, we can possibly get a lagoon at 10°C to function as well as one at 20 or 25°C. But the kinetics of reproduction in microorganisms are not likely ever to reach a higher rate with the psychrotrophs than with mesophiles.

Little is known about the nutrient requirements and cell yield coefficients of the psychrotrophic bacteria. One might assume that their phosphorus requirement is lower than that for mesophilic bacteria because of their slower reaction rates.

**Studies conducted at the Inuvik, N.W.T., sewage lagoon from July to November 1984.** In these studies, funded by Indian and Northern Affairs Canada (D. Prasad, University of Toronto), emphasis was placed on the microbiological aspects by determining the concentration of psychrotrophic bacteria present in the liquid and the sediments at 1°C.

Psychrotrophic bacteria are known to form a substantial portion of the microflora present in wastewater treatment processes operating at low temperatures.

Site Description. The Inuvik sewage lagoon (latitude 68°22'N longitude 133°43'W) was upgraded in 1982 from a one-stage system to a two-stage system. The lagoon system consists of two 1.3-ha primary cells, (average liquid depth: 1.3 m), in parallel, followed by a 20-ha secondary cell (average liquid depth: 1.2 m). The lagoon system is designed to receive 2000 $m^3/d$ of raw wastewater from a population of 3200 (625 L/p•d). Wastewater from the serviced area is collected in utilidors and then flows by gravity through a collecting sewer to the primary cells (detention time: 17 days). Here settlable solids are retained and stored. The effluent from the primary cells then enters the secondary cell where it is held for about 10 months (from November through August). During early winter (September and October), the secondary cell is drained and the effluent discharged into the East Channel of the Mackenzie River. By mid-winter, except for an area around the inlet, the lagoon is covered by 60 to 80 cm of ice.

Collection of Samples and Analytical Procedures. Samples were taken over the first week in August 1984 and again during November 1984. These periods were intended to represent the summer (ice free) and the early winter (ice covered) periods of lagoon operation. Summer samples were collected from the primary and secondary cells at two levels (0.5-m and 1.0-m depths) by means of a water sampler. Samples at the inlet and outlet structures were single grab samples.

Sample locations were at the inlet (influent), at the centre of each primary cell, the 1/3 and 2/3 points of the secondary cell and at the outlet structure (effluent). The November samples were collected through a hole (20 cm in diameter) cut in the ice with an auger. Only one water sample was taken from mid-depth at each sampling station. Sludge samples were taken from the bottom sediment with an Ekman sampler. In August, the sludge sampler was dropped into the water and allowed to hit the lagoon bottom. Sludge samples thus contained sediment from the top few centimeters of the lagoon bottom. The temperature and dissolved oxygen of the lagoon were recorded when each sample was taken. Most of the chemical and bacteriological analyses were done in duplicate, in accordance with Standard Methods APHA, 1981. The number of viable bacteria was determined by the dilution spread-plate method, using nutrient agar (Difco). Plate counts for total counts were made after 7 days of incubation at 20°C , and after 14 days of incubation at 1°C for psychrotrophic bacteria.

Results. Some of the wastewater and lagoon water characteristics are given in Table 4.

Physical and Chemical Data. Water temperature readings in August for both the primary and the secondary cells differed by only 1°C. The maximum temperature recorded in August was 17.5°C. The temperature during November in both cells ranged between 0 to 1°C).

The dissolved oxygen in the primary cells was always low, less than the detectable limit for the method used. In the secondary cell in late summer, however, dissolved oxygen ranged between 6.4 and 9.2 mg/L. In November, with an ice cover on the secondary cell, DO dropped to zero.

In summer, the pH was higher in the secondary cell than in the primary cells, otherwise only minor changes in pH were observed.

The average total alkalinity, measured as $CaCO_3$, was about 156 mg/L in the summer samples and 180 mg/L in the winter samples; there were no significant differences between the primary and the secondary cells.

In the summer sampling period the total solids (TS) ranged between 300 and 370 mg/L and the corresponding volatile solids ranged between 122 and 188 mg/L. The average solids concentration of the cell contents, derived from Table 4, is shown in Table 5.

During both sampling periods the total solids concentrations were greater in the secondary cell. By early winter the total solids concentration increased in the secondary cell, and the percent volatile solids had increased in both the primary and secondary cells.

The average measured BOD and chemical oxygen demand (COD) values with respective percent removals are shown in Table 6.

The BOD removal efficiency of the Inuvik lagoon system was 90 percent in the summer and dropped to 80 percent by November. During both periods the primary cells accomplished about half of the overall BOD and COD removals, assuming that the BOD removal in the secondary cells is not attributable to sedimentation. Significant degradation of soluble organics is taking place even during the cold month of November.

Microbial Data. Total bacterial counts in the raw sewage ranged from 2.44 x $10^6$/mL (November) to 10.24 x $10^6$/mL (summer). The summer to early winter difference in counts was wide for both total count and psychrotrophic count in the primary cells but less noticeable in the secondary cell. In the summer, the total bacterial population in the primary cells was high (102 x $10^6$/mL), and showed the greatest decline (more than two orders of magnitude) under early winter conditions. However, no winter decline occurred in the secondary cell. The average total bacterial counts in the secondary cell were 0.66 x $10^6$/mL in the summer and 0.65 x $10^6$/mL in the winter.

The numbers of psychrotrophic bacteria in the raw sewage were approximately the same (52 x $10^3$/mL) during both seasons. In the primary cells the psychrotrophs were

TABLE 4 PHYSICAL AND CHEMICAL PARAMETERS AT SAMPLING STATIONS IN INUVIK SEWAGE LAGOON SYSTEM

| Sampling point | Air temp. (°C) | Total depth (m) | Solids (mg/L) | VS (%) | Water temp. (°C) | DO (mg/L) | pH range | Total Alk. (mg/L) |
|---|---|---|---|---|---|---|---|---|
| Summer | | | | | | | | |
| (July 31-Aug. 9) | | | | | | | | |
| Influent | 22 to 24 | - | 328 | 37 | 18.5-19 | 0 | 7.1-8.3 | 150 |
| Primary Cell 1 | 22 to 24 | 3 | 300 | 51 | 15-17.0 | 0 | 7.0-7.1 | 162 |
| Primary Cell 2 | 22 to 24 | 2.8 | 320 | 59 | 15-16.5 | 0 | 6.9-7.3 | 140 |
| Secondary Cell[a] | 22 to 24 | 2.6 | 330 | 52 | 16.5-17 | 6.4-8.9 | 7.5-7.9 | 162 |
| Secondary Cell[b] | 22 to 24 | 1.5 | 370 | 42 | 16.5-17.5 | 7.9-9.2 | 7.7-7.9 | 162 |
| Effluent | - | - | 370 | 33 | 17-17.5 | 8.75-9.2 | 7.6-7.7 | 163 |
| Early Winter | | | | | | | | |
| (Nov. 23-Nov. 28) | | | | | | | | |
| Influent | -20 to -30 | - | 435 | 45 | 10 | - | 7.6-7.65 | 133 |
| Primary Cell 1 | -20 to -30 | 3 | 270 | 74 | 0 to +1 | 0 | 7.0-7.10 | 172 |
| Primary Cell 2 | -20 to -30 | 2.8 | 340 | 70 | 0 to +1 | 0 | 7.1-7.2 | 172 |
| Secondary Cell[a] | -20 to -30 | 1.5 | 380 | 78 | 0 to +1 | 0 | 7.2-7.3 | 194 |
| Secondary Cell[b] | -20 to -30 | 1.5 | 420 | 82 | 0 to +1 | 0 | 7.2-7.3 | 194 |
| Effluent | -20 to -30 | - | 390 | 90 | 0 to +1 | - | .30-6.30 | 196 |

[a] Sample taken at the one-third point of the cell

[b] Sample taken at the two-third point of the cell

TABLE 5 AVERAGE SOLIDS CONCENTRATION OF CELL CONTENTS

| Summer | Total Solids (mg/L) | Volatile Solids (mg/L) | Volatile Solids (%) |
|---|---|---|---|
| Summer | | | |
| Primary cell | 310 | 170 | 55 |
| Secondary cell* | 357 | 147 | 42 |
| Early Winter | | | |
| Primary cell | 305 | 220 | 72 |
| Secondary cell* | 397 | 330 | 83 |

* includes effluent

TABLE 6 AVERAGE BOD AND COD VALUES (avg. of 4 samples)

| Sampling Point | BOD (mg/L) | Removal (%) | COD (mg/L) | Removal (%) |
|---|---|---|---|---|
| Summer (July 31 - Aug. 9) | | | | |
| Influent | 120 | | 290 | |
| Primary cell 1 | 60 | | 160 | |
| Primary cell 2 | 60 | 50 | 200 | 38 |
| Secondary cell (at 1/3 point) | 12 | | 75 | |
| Secondary cell (at 2/3 point) | 10 | | 70 | |
| Effluent | 11 | 90 | 68 | 76 |
| Early Winter (Nov. 23 - Nov. 28) | | | | |
| Influent | 138 | | 290 | |
| Primary cell 1 | 82 | | 200 | |
| Primary cell 2 | 84 | 40 | 220 | 28 |
| Secondary cell (at 1/3 point) | 60 | | 160 | |
| Secondary cell (at 2/3 point) | 42 | | 140 | |
| Effluent | 26 | 81 | 120 | 59 |

about 74 x $10^4$/mL in the summer, and showed a slight decline to 24 x $10^4$/mL in the winter. This change indicates a shift in microbial population from predominately mesophiles in the summer to psychrotrophs in November when the lagoon water temperature varied between 0 and 1°C.

In Table 7 further observations, regarding the presence and absence of the mesophiles and psychrotrophs, are listed.

TABLE 7 BACTERIAL COUNTS ($10^6$/mL) BY TYPE

| Sampling Point | Total Bacterial Count | Psychrotrophs (%) | Mesophiles (%) | Total Psychro-trophs | Total Meso-philes |
|---|---|---|---|---|---|
| Primary Cells | | | | | |
| Early Winter | 0.8 | 30 | 70 | 0.24 | 0.56 |
| Summer | 102 | 0.75 | 99.25 | 0.74 | 101.23 |
| Secondary Cell | | | | | |
| Early Winter | 0.65 | 84 | 16 | 0.55 | 0.10 |
| Summer | 0.66 | 0.5 | 99.5 | 0.003 | 0.657 |

1. In winter, the total count of psychrotrophs ($10^6$ mL) increased in the secondary cell from the primary cells (0.55 from 0.24) (growth) with dissolved oxygen measuring 0 mg/L in both cells.
2. In the summer, the total count of both mesophiles and psychrotrophs were lower in the secondary cell than those in the primary cell because of differences in loading.
3. In the primary cells the total count of psychrotrophs decreased from summer to winter conditions as did the mesophilic count (lower growth at low temperature for both).
4. In the secondary cell the total count of mesophiles increased in summer from winter while the count of psychrotrophs decreased. (Mesophiles prefer the warmer temperatures).

**Lagoon sludge characteristics.** Another objective of this study was to examine the seasonal changes in sludge composition in an effort to clarify what role, if any, the sludge plays in the treatment of wastewater.

TABLE 8 CHARACTERISTICS OF THE ACCUMULATED SLUDGES FROM THE INUVIK SEWAGE LAGOON SYSTEM

| Season and Sampling Point | Sediment Temp. (°C) | pH | Total Solids (mg/L) | Volatile Solids | | Total Counts (x $10^8$/g) | Psychrotrophs | |
|---|---|---|---|---|---|---|---|---|
| | | | | Total | % of TS | | (count x $10^6$/g) | (%) |
| Summer | | | | | | | | |
| (July 31 to Aug. 9) | | | | | | | | |
| Primary cell 1 | 4-6 | 6.5 - 6.5 | 25 400 | 16 010 | 63 | 7.70 | 20.45 | 3.2 |
| | | | 17 700* | | | 11.12* | 41.1 | |
| Primary cell 2 | - | 6.6 - 6.7 | 10 800 | 5 900 | 59 | 14.65 | 61.80 | 4.2 |
| Secondary cell[a] | - | 6.6 - 6.7 | 13 800 | 5 934 | 43 | 16.3 | 53.80 | 3.3 |
| | | | | | | 11.7* | 35.8 | |
| Secondary cell[b] | - | 7.3 - 7.3 | 3 800 | 1 558 | 41 | 7.15 | 17.95 | 2.5 |
| Early Winter | | | | | | | | |
| (Nov. 23 - Nov. 28) | | | | | | | | |
| Primary cell 1 | 0-1 | 7.1 - 7.35 | 19 400 | 6 790 | 35 | 0.89 | 24.48 | 27.5 |
| | | | 18 400* | | | 0.78* | 22.03 | |
| Primary cell 2 | " | 6.8 - 6.9 | 17 400 | 5 220 | 30 | 0.67 | 19.58 | 29.2 |
| Secondary cell[a] | " | 7.05 - 7.20 | 13 200 | 6 072 | 46 | 1.16 | 93.7 | 80.8 |
| | | | | | | 1.21* | 159.7 | |
| Secondary cell[b] | " | 7.25 - 7.30 | 8 400 | 4 872 | 58 | 2.54 | 225.75 | 88.9 |

* Average values

[a] Sample taken at one-third point of the cell

[b] Sample taken at two-third point of the cell

The following observations are made from the results shown in Table 8.

Chemical Data.

1. For both sampling periods, the total solids in the sludge from primary cell 1 was higher than those from primary cell 2.
2. For both sampling periods, the total volatile solids in the sludge samples from primary cell 2 and the inlet end of the secondary cell were similar.
3. For both sampling periods the total and volatile solids in the sludge samples near the outlet end of the system were the least.
4. By November, the average total solids in the liquid decreased while the concentration of volatile solids increased.
5. By the November sampling period, the total and volatile solids in the vicinity of the secondary cell outlet had increased (perhaps due to dead, settled algal mass.)

Microbial Data.

1. In summer, the total bacterial populations in the sludge samples were extremely high with no significant difference in the number of bacterial counts between primary and secondary cells.
2. The total bacterial count decreased by one order of magnitude in the winter in all cells. The average bacterial counts were about 11 x $10^8$/g (dry weight) in the summer and 0.8 to 1.2 x $10^8$/g (dry weight) in the winter.
3. The average number of psychrotrophs (41 x $10^6$/g (dry weight)) in the sludge from the primary cells in the summer decreased to two-fold (22 x $10^6$/g (dry weight)) in November. However, the psychrotrophic counts in the secondary cells increased about 3.5-fold in early winter and reached 160 x $10^6$/g (dry weight).
4. The proportion of psychrotrophs in the summer sludge samples remained at about 3 to 4 percent, even though the temperature (4 to 6°C) of the sediment was in the range that is normally selective for psychrotrophs. The percentage of psychrotrophs in the summer was only in the 0.5 to 0.75 range at water temperatures of 15 to 18°C. It is possible that the psychrotrophs were under stress because of the higher temperature in the upper water layer. In November, the proportion of psychrotrophs in the sludge increased significantly: in the primary cells by 28 percent and in the secondary cell by 85 percent.

**Conclusions.** High BOD removal (80 percent) during early winter and the presence of a psychrotrophic population in significant number in lagoon water and sludge sediment support the hypotheses that the degradation of organic waste matter in these arctic lagoons is performed by bacteria that are able to grow and metabolize at low temperature.

The low proportion of psychrotrophs (4 to 5 percent) in the summer sludge sediments, where temperatures remain low enough to be selective for the psychrotrophs, was somewhat surprising. However, it is consistent with a similar phenomenon noted in the mixed liquor of an aerobic digester operated at low temperature (5°C) by Henry and Prasad in 1981, where the psychrotrophic bacteria remained at less than 1 percent of the total viable bacterial population.

The reasons for the high winter efficiency are being pursued in ongoing studies but the preliminary data indicate psychrotrophic bacteria to be one of the major contributing factors. Although the total bacterial count in the secondary cell was similar under both winter and summer conditions, the percentage of psychrotrophs increased from less than 1 percent to over 80 percent with the change in season. The presence of psychrotrophs in substantial numbers is an indication of their importance during winter operation of the lagoon.

**3.5.11 Lagoon Configuration.** The efficiency of stabilization depends not only on organic loading, temperature, etc. but also on lagoon geometry, size, and number of cells:

a) In the design of lagoons, we know that if we increase the number of reactors or cells, then the mixing regime changes from completely mixed flow (CMF) to plug flow (PF). Therefore a single CMF reactor can be viewed as a number of PF reactions in series. This gives a better performance as for BOD and SS removals are concerned. For example, effluent from a 7-celled lagoon did not exceed 30 mg/L total BOD compared to a 3-celled lagoon which could not deliver quality effluent in winter months. Higher microorganism removals have been reported in some countries, such as South Africa, by multicell lagoons. As for the optimum number of cells for best performance, there is no precise information but it is generally agreed that three cells are highly recommended, although two cells are a minimum. Hydraulic modelling may be one of the methods to find a solution to this important problem.

b) As we know, short-circuiting is one of the major problems encountered in lagoon practise. The best way of solving this problem is to place cells in series. However, the question of economics has to be borne in mind while choosing the number of cells. Baffles (surface and submerged in-depth) function satisfactorily in summer months but as winter ice interferes with their operation. This area needs more study.

c) Lagoon geometry is found to influence the rate of dispersion in the lagoons which consequently controls the complete-mix conditions. There is some disagreement, however, on this issue. Quite often, lagoon geometry is dictated by the available land configuration. Authors, such as Middlebrooks et al., have suggested that rectangular tanks having a length/width ratio of 1:1 to 2:1 would provide best plug flow conditions. Some recommend a 3:1 ratio to produce similar results.

d) For series and parallel operation, adequate control mechanisms, including pipes and valves, have to be installed at the time of lagoon construction.

e) Discharge of effluent can be continuous, intermittent, or non-existent (controlled and total retention). Continuous discharge lagoons require less land and operating time than controlled discharge lagoons. Lagoons are operated in parallel especially in winter for distributing organic loading. For best operation the lagoon can function in series all summer and in parallel during winter. Operator skills are a prerequisite for best performance of the system throughout the year.

Intermittent autumn and spring discharges are possible options. Autumn discharge is found to be preferable because receiving waters are often higher during this season and the quality of effluent is quite satisfactory (few algae, low ammonia, and low BOD). The correct time and control of rate of discharge has to be determined to protect receiving streams. Use of hydrographs for determining the best time of discharge has been suggested in literature. Other equally effective methods have to be studied.

Total retention systems rely on seepage and evaporation to maintain a liquid balance in the lagoon. The advantage of this method is that no discharge to a receiving stream or no operator attention to a land surface is required.

**3.5.2 Facultative Lagoon Models.** Lagoon models attempt to simulate the reactions that take place in the lagoon environment. The goal is to provide the design engineer and operator with a rational means to determine lagoon behaviour in response to various environmental design and operation conditions.

The performance of a waste stabilization pond depends on the following factors: influent qualities, temperature of the liquid, available solar energy, surface area, organic load, volumetric BOD load, pond shape and size (length, width, depth, diameter), flow regime (plug, completely mixed, dispersed plug flow, etc.), mixing and dispersion due to wind stratification, number of cells, evaporation, precipitation, infiltration, exfiltration, ice and snow cover, short-circuiting, hydraulic retention time, and benthal load. It is no wonder that a precise formula is not currently available to represent all these variables.

An oversimplified formula or model, though convenient to use, may not be precise enough for design use. At the other extreme, a complex model characterized by a series of complicated formulas may be too unrealistic and time-consuming to apply. Therefore, we should focus on identifying a middle course which should include a design procedure based on sound theory but simple enough to be practical.

'Black box' statistical models, hydraulic models, and biochemical process models have been developed which assume continuous discharge and hydraulic regimes between plug flow and completely mixed flow. The empirical approach is based on observations of existing systems resulting in first-order approximations for BOD removal, bacterial reduction, and nutrient removal. Rate constants for these approximations may be derived from laboratory or field studies, or both.

Empirical models include those of McGarry/Pescod and Gloyna. The McCarry/Pescod regression equation developed for high organic loading rates with no account for temperature or pond depth is not suitable for cold regions. Gloyna's empirical equation has found wide acceptance, because it considers important parameters but gives erratic results when applied to cold-climate lagoons. The problems found when using this model for our northern environment are probably due to sunlight conditions different from those found in the southwestern United States for which it was developed.

Some of the analytical models include those of Marais, Oswald, and Thirumurthi. Thirumurthi's first model, presented in 1969, uses the dispersed flow approach of Wehner and Wilhelm (1956) to simulate non-ideal flow between plug flow and completely mixed flow. The value of the dispersion number "d" which varies from time to time due to environmental factors may be approximated from the Thirumurthi design chart but should be determined from tracer studies in ponds with a geometry similar to the one being designed. Poor correlation with data observed in the northern U.S. lagoons has been attributed to short circuiting and poor evaluation of the overall $BOD_5$ removal rate constant. Thirumurthi's plug flow model ($d = 0$), presented in 1974, introduces a correction factor for organic load (CO) that takes into account available solar energy for algal photosynthesis.

Appendix D-3 gives a summary, prepared for the workshop by Dr. Thirumurthi, of the various design models for facultative continuous flow lagoons.

Several investigators have monitored field lagoons and attempted to verify the existing design models by using their collected data (see Section 3.6.3). None was found to be adequate. The empirical design equations, as well as the kinetic design models, yielded predictions not substantiated by the published data on pond performance.

None of the models differentiates between settlable BOD and dissolved BOD in the influent wastewater. Focussing attention on this factor is important because stabilization of dissolved organic matter is brought about by aerobic microbes and algae and the stabilization of settled organics mostly by anaerobic microbes in the lower layers.

Hydraulic factors, such as evaporation, precipitation, infiltration from the ground, and exfiltration into the subsurface environment, are not included in the current design equations. Because these factors tend to either dilute or concentrate wastewater, they should be incorporated in the models.

Further studies are needed on the anaerobic decomposition of the bottom sludges to determine a correction factor for the effect(s) of the benthal load on lagoon performance. Readily available design formulas based on a proper understanding of the theory and mechanisms of the complex physical, chemical, and biological interactions, which take place in the lagoon environment, would enable the rational design of efficient and cost-effective cold-climate sewage lagoon systems.

## 3.6 Lagoon Design

**3.6.1 Site Selection.** Before looking for a lagoon site, the design engineer must have some insight into the acrage required for the size and industrial base of the community. While doing a preliminary screening for suitable sites, the engineer should seek out all related, existing information available from various sources. Topographical maps, aerial photographs, hydrological and geotechnical data are all useful.

The next step in finding a suitable site for a lagoon is to learn the preferences of the Mayor, the Council, and the works department (municipal employees).

Residents in the community may be aware of adverse features of a proposed site such as maximum flood levels, bedrocks, predominant wind direction, and any development plans by owners or other utilities.

Once this preliminary information and local input have been obtained, it is necessary to do a detailed analysis including an on-site geotechnical survey to determine the presence or absence of rock, permafrost, groundwater, and the soil characteristics.

On the prairies there is seldom a real problem with the topography because the land is flat. Elsewhere the topography plays a major role in choosing the site and influences the number and shape of cells.

Besides choosing sites agreeable to the regulatory authorities and the community, project costs must be affordable. Other factors which affect costs are the availability of electrical power and access roads.

**Isolation distances.** The main reason for siting lagoons at some distance from habitations is to minimize odours in the communities which they serve and to discourage trespassing on the site itself. The lagoon site should be compatible with long-range planning so that growth is not constrained. Even without planning, growth often takes place in the direction of the waste treatment facility, once the new trunks sewer and access road have been installed. Generally lagoons should be sited as far away from the communities they serve as possible. Siting distances permissible by regulations should be considered minimums not maximums.

In Manitoba, lagoon siting has been decided by the community, the consultant and the environmental regulatory authority. Approvals will soon be given on a land use basis in accordance with regional plans, subdivision plans' and other requirements under municipal planning acts and regulations. In Manitoba a buffer zone is required even when lagoons are sited in agricultural land. A 30-m buffer zone around the lagoon is required as a precautionary measure not because of odours but because of other factors, seepage among them.

Ontario also sets minimum separation distances which tend to be used as standard regardless of the type of wastewater being treated.

In Quebec waste treatment facilities are usually being installed to serve municipalities with existing sewer systems so the only feasible site is at the lowest point in town. It is almost impossible to be 150 m away from the nearest residence. Aerated lagoons are built with a preferable distance of 300 m from existing housing. In some cases when this criterion cannot be met, the distance can be reduced to 150 m, if other factors, such as wind direction, etc., are favourable. Non-aerated lagoons are required to be 600 meters from habitation.

Since 1979, lagoons in Quebec require approval under agricultural land use regulations as well as environmental approval with respect to effluent quality and point of discharge. Lagoons must also be located beyond the 100-year flood zone of receiving rivers.

Some feel that the communities themselves should decide the degree to which they want to subject themselves to odours once they have been made aware of this disadvantage of lagoon systems. However, with time, councils change and residents change. Basically no one wants a lagoon system which interferes with land use and gives off objectionable odours.

Zoning by-laws to restrict development of at least residential properties within the recommended buffer zone and along roads in the lagoon areas are desirable. For example, in the City of Winnipeg, the Water Works Waste and Disposal Department has been objecting to development toward the vicinity of its lagoons and even its mechanical treatment plants. But the lands in question are privately owned. In one incident a developer had bought land near the south-end treatment plant. The Department stepped in to say that it did not want any development near that treatment plant. The developer said, "Okay, compensate me for the land you have confiscated". It's really the municipality that owns that land. The Inuvik lagoon is also an example of where subsequent housing construction was allowed to encroach on the area of a lagoon installation.

For lack of ways to prevent or curtail odours lagoons are sited as far away from town as affordable. Inhabitants oppose large lagoon systems for fear of odour problems. Lagoons as a method of municipal waste treatment could be even more cost-effective, if odours could be controlled.

One must remember that isolation distances also have an important safety aspect in minimizing not only harm to human life, wild fowl, and farm animals but also willful damage. This is especially true for small systems serving rural residential developments and institutions.

**Litigation over odour complaints.** The problem has reached the point in agriculture where litigation may cause the closure of some farm operations.

Currently, litigation is occurring in at least two instances in B.C. One wonders whether anybody has sued a municipality in Canada because odour is a nuisance. If not, then it is just a question of time.

- The City of Portage la Prairie was sued back in the 1960s. The suit involved two problems: one was seepage and the other one was odour. The City lost in terms of the seepage, they won in terms of the odour. It didn't help them any, but apparently the judge felt the evidence indicated that you can't have a lagoon without odour. It seems to be accepted as an integral part of the operation. So, they managed to get off on that one.
- There have been two incidents in Alberta. One was an operator in Jasper National Park located next door to the Bard lagoon treatment system. He sued the Federal Government for loss of business because of the odours every spring. He won; so as a remedy, aeration was added to the lagoon system. Another one involved the Calgary International Airport. It does have a lagoon, but it has a one-cell storm water management pond. The airport was requested by the City of Calgary to do something about the $H_2S$ problem every spring. So they also added aeration equipment.

**3.6.2 Construction in Permafrost Regions.** In the Arctic particularly, one cannot overemphasize the need for geotechnical expertise when siting, designing, and constructing lagoons in permafrost. Permafrost underlies slightly more than 50 percent of the land area of Canada. One does not have to go very far north to find it. The discontinuous zone extends across the northern parts of all the prairie provinces. For example, its southern boundary is only 320 km north of Winnipeg and south of the north-end of Lake Winnipeg. It is found south of the south-end of James Bay in Ontario and Quebec. It also occurs at elevation in the Rocky Mountains, in Newfoundland, and the Gaspe Bay. In the continuous zone the permafrost appears everywhere under the land surface and under many small lakes and streams.

**Finding a suitable site.** Site selection for a lagoon is most important so that permafrost is to be avoided if at all possible. Unfortunately, in the discontinuous zone, permafrost is usually found in the low-lying areas. Even if pumping will be required, the lagoon should be sited on higher ground to avoid any problems from permafrost.

Another factor is that many communities in the Canadian high-arctic are located along the sea coast. As a result of isostatic rebound and glaciation, these communities are under lain by saline, frozen soils. Soil temperatures will be below freezing, sometimes -2 to -3°C. These are then frozen materials which do not exhibit ice conditions, but if used for construction could cause problems particularly when building an impervious embankment.

The site investigation should also determine the best available core materials for stability of the embankments. Two ways of building an impervious dike in terms of the potential thermal regimes are shown in Figure 9 of "Sewage Lagoons in Cold-Climates", Report EPS 4/NR/1 March, 1985, p. 9.

**Avoiding thawing problems.** Some of the problems that arise with the construction and performance of structures on permafrost are the result of the moist perennially frozen soil. The soil contains ice as well as rocks and gravel. These ice-rich materials cause thaw-settling problems, when a heat source above thawing temperature comes in contact with the ground. Thaw-settling means differential movements. Such movements may, in turn, cause erosion and pipe breakage problems.

Most of northern Canada was glaciated and therefore the designer is faced with glacial deposits, silts, sandy silts, fine sands, and till which may be dense or loose, stoney or non-stoney. In some cases one may be dealing with peat deposits. These are sometimes thick, but usually they provide a very thin covering over the ground surface.

All these are generally highly undesirable as construction materials because they are frequently frozen and contain ice. This is particularly so with seasonably frozen materials which are frozen 8 or 9 months of the year but are subject to thawing during the summer period. The underlying permafrost remains frozen throughout the year.

These materials are difficult, if not impossible, to compact particularly when used in a frozen condition. Because of their high water content, they are also difficult to work with upon thawing. They may need some processing before they can be used in an impervious structure such as a lagoon berm.

During the winter, with lack of sufficient snow cover, frost penetration may occur down into the embankment, particularly on the outside edge. Any seepage is going to be attracted to the frozen core where it forms ice lenses. If the berm material is very porous and the base is porous, the hydraulic grade line will reach the water table. Often, however, moisture migrates to the freezing front. It is therefore necessary to make sure the amount of moisture migrating is small enough to prevent large ice lenses from forming. So leakage control includes more than just preventing the accumulation of liquid around the base of the lagoon.

In the discontinuous zone and in some southern parts of the continuous zone, thawing under lagoons or their embankments cannot be prevented. The designer is faced with a thaw condition which requires placing an impervious barrier in the embankment or making the total embankment impervious. In the continuous zone, the construction of impervious frozen embankments can be considered.

Development of the site and scheduling of construction must be done carefully and well in advance. Construction equipment may have to be brought in, if local equipment is unsuitable. For small northern communities the best practical technology is expressed in terms of lagoon configuration rather than maximum effluent concentrative criteria (BOD, SS, etc.) or "secondary treatment". This boils down to specifying the required retention times for each type of cell. Requirements for secondary treatment using lagoons have been defined in terms of configuration and retention times rather than by effluent quality specifications. All involved - from the site investigator, to the designer, to the contractor, and to the operator - must be aware that a lagoon with its impervious dikes is expected to be structurally sound for many years ahead.

**3.6.3 Facultative Lagoons.** A number of approaches have been used to design conventional facultative lagoon systems:

- organic loading criteria,
- retention time criteria, and
- empirical/analytical models.

Organic Loading Criteria. In Canada, provincial regulatory agency organic loading criteria range between 22.4 kg BOD$_5$/ha·d and 56.1 kg BOD$_5$/ha·d.

The lower loading rates are used to achieve effluent quality in the 10 to 15 mg/L BOD$_5$ and 10 to 20 mg/L SS range and to minimize odours during spring break up. In Alberta and Manitoba, where the higher loadings are used, effluent quality is expected to be in the 30-mg/L BOD$_5$ and 50-mg/L SS range.

Some designers consider the main question is indeed the maximum permissible organic loading to achieve the desired effluent quality without creating unacceptable odour conditions.

Retention Time Criteria. Organic loading criteria alone have been shown to be inadequate under cold-climate, continuous flow conditions to produce acceptable effluent quality except during the warm summer months. Most jurisdictions now use a minimum residence time as the controlling design requirement.

With respect to retention time, some of the latest published information suggests at least 120 to 150 days even in fairly good environments. For cold-climates, we should be dealing with 180 days to a full year of retention time. In Alberta, 365 days of retention is becoming a standard. This storage requirement may be reduced only if:

(i) wastewater irrigation is practiced, in which case storage may be reduced to 7 or 8 months, or

(ii) if storage is headed by mechanical secondary treatment, in which case storage may be reduced to 7 months.

In Alberta, process design is looked upon differently for lagoons in the southern half of the Province from lagoons in the northern half. In the South, where the climate is hotter and drier, there is a demand for treated sewage as a resource for irrigation purposes, therefore shorter retention lagoons are accepted.

Sampling. Treating the overall lagoon system as a reactor means that it should be treated as a plug flow process and not a series of squares or big circles; to have any faith in collected data-sampling for a completely mixed reactor, samples should be taken over a number of retention times to start relating to the influent what is reported as effluent quality.

- For a completely mixed reactor six retention times are required for all the many components of the influent, to be essentially discharged as effluent. The curve is an exponential one.
- For a true plug flow system or any type of partially mixed system in which you don't know what the mixing system is, several - say, four - retention times are required before the data can be related back to the effluent.

Considering that BOD reduction follows first-order kinetics, then the optimum would require three to four completely mixed cells in series to provide the lowest volume retained while achieving the highest effluent quality. But reaction rate coefficient "K" is seldom known, especially from one cell to another. Satisfactory operation can be achieved in one completely mixed cell but it would be larger in volume then the three individual cells. So, similarly you get good operation from two cells, but it still would not be an optimum design.

Determining the optimum number of cells to minimize capital expenditure and maximize effluent quality comes down to knowing the reaction rate coefficients, making some assumptions on the mixing regime - how close the design approaches plug flow as opposed to complete mixing because optimum design requires plug flow.

Empirical/Analytical Design Models. Almost all existing design equations assume steady-state conditions (constant qualities of influent stream, constant environmental factors such as solar energy, temperature, wind speed, etc.). Such assumptions facilitate simple and convenient design models. On the other hand, as all these parameters vary from hour to hour and day to day, it becomes unrealistic to expect precise predictions from these models. Unless a computerized program, incorporating all these variables, is employed with a systems approach, the design engineer may never have a precise formula to predict effluent quality.

Dr. Thirumurthi stated that most of his modelling work was on continuous discharge lagoons in warmer climates (Texas, Miami, Florida, and southern India). Appendix D-4 provides an edited version of Dr. Thirumurthi's paper "Design Criteria for Waste Stabilization Ponds" Journal of the Water Pollution Control Federation, 1974, 46(9) pp. 2094-2106. As reported in "Design Manual - Municipal Wastewater Stabilization Ponds", EPA 625/1-83-015, Oct. 1983, when Middlebrooks monitored three facultative lagoons in northern U.S.A. he found out that none of the models are precise.

Dr. Thirumurthi reported that for continuous discharge lagoons under Nova Scotia conditions his model, using a standard BOD removal coefficient K of 0.055 per day at 20°C, gives good results. Influent BOD loadings of 22.4 kg/ha•d give 90 percent BOD removal in the summer and about 80 percent BOD removal in the winter.

Solar energy for algal photosynthesis is a very limiting factor in ice- and snow-covered lagoons. The solar energy falls below the assumed available southern standard of 8 langleys/kg BOD•ha•d. Actual values for northern Canada result in a negative organic load correction factor (CO) rendering Dr. Thirumurthi's present model inapplicable. Dr. Thirumurthi also pointed out that his model does not apply to intermittently operated lagoons.

With so many factors affecting lagoon performance, Dr. Thirumurthi does not expect that we will ever have a model or equation which is going to precisely predict the actual effluent quality. We can try to improve on the existing models to be within plus or minus 20 percent of actual performance.

Cell Types and Lagoon Configuration. Lagoon systems come in a variety of forms, configurations and discharge modes. Different cells have different functions to perform.

Small cells at the beginning of a lagoon system have a function different from the larger storage cells at the end. It is not necessarily optimal to design all cells with the same size and shape. There has to be some differentiation to optimize the function of different cells.

Shortly we will consider preaeration cells, anaerobic primary cells, facultative treatment cells, and polishing or storage cells.

**Primary anaerobic cells.** These smaller cells are placed ahead of the main treatment cells to:

- keep the temperature as high as possible at the front end of the system;
- provide flexibility in the accumulation and removal of settled solids as sludge; and
- reduce the loading on the main treatment cells.

Performance. Anaerobic cells in cold-climates are expected to provide $BOD_5$ and SS removals equivalent to primary treatment. Data presented from sampling the Whitehorse anaerobic lagoon which treats dilute wastewater over 9 winter months, showed $BOD_5$ removal of 30 to 40 percent, suspended solids removals of about 50 percent, and coliform reductions of 70 percent.

Design Criteria. Present design criteria are based on practical construction techniques and the realization that odours get out of control when cells are made too large. Anaerobic cells are designed on a basis of retention times between 2 to 5 days. The potential for odour problems increases with longer retention times.

The depth and size of anaerobic cells are based on practicalities. Depths from 3 to 8 m are used. Where wastewater flows are less than 13 kL/d, constructing a cell of standard configuration is not feasible because it is physically impossible to build them 3 m deep with side slopes of three horizontal to one vertical to provide retention times of 4 to 5 days. Also construction equipment cannot manoeuver in such small, deep cells. Anaerobic cells for small communities therefore tend to be oversized which contributes to the formation of odours.

In Alberta, for small systems it is now proposed to forgo the deep anaerobic cells and divide the shallow, 60-day (1 to 5 m) treatment pond into two or three cells, the first one small enough to ensure submergence of the inlet piping to prevent freezing problems.

Alberta Environment recognizes that anaerobic cells add significant costs to large systems and that they contribute to the odour problem. But because of their contribution to the treatment process, Alberta Environment has no intention of eliminating them in its design standard.

**Preaeration cells.** Small preaeration cells may also be installed ahead of the main treatment cell to:

- reduce the loading on the main treatment cells,
- control odours, and
- accumulate settled solids as sludge where incomplete mixing is provided.

The whole concept of installing a preaeration cell is to provide some intense oxygen input for BOD reduction and odour control in a much smaller area or a much smaller volume.

Energy applied in the range of 1.64 to $2.46 W/10^3 L$ may provide uniform oxygen distribution in aerated cells, but it is not sufficient to uniformly maintain the settlable solids in suspension.

More information on design and aeration equipment is contained in Section 3.6.4 on "Aerated Lagoons".

**Main treatment cells.** These are the facultative cells upon which conventional sewage lagoons are based. They may consist of one cell or be in number of cells in series and parallel. Usually they are 1.5 to 2 m deep. Depending upon where they are located in Canada, they might have at least a 60 day retention time and organic loadings between 22.4 kg $BOD_5$/ha•d and 56.1 kg $BOD_5$/ha•d when treating raw wastewater. When preceeded by anaerobic or aeration cells the organic loading is reduced by at least 30 percent.

When followed by storage ponds, the main treatment cells may be used to prevent short-circuiting when they are drained.

The following design considerations apply to all sewage lagoon systems utilizing facultative cells for treatment and storage:

- When required to provide a specific retention time, establish whether this is based on the total volume at maximum liquid level or whether an allowance must be made for the "dead" volume below the minimum operating level. Usually net precipitation, infiltration, seepage, and berm leakage are not taken into account;
- Make provisions for future expansion;
- Determine and allow for the impact of industrial waste inputs in the system;

- Provide flexibility in piping arrangements for series and parallel operation and liquid level control. Such arrangements should permit drawdown of cells for repairs to the berms and isolation of cells for sludge removal;
- Locate flow control structures to one side of the berm rather than in the centre for unobstructed vehicle access;
- Avoid the use of stop logs to control liquid levels by using other means such as a valved, upturned T pipe for liquid level control including complete drainage;
- Make adequate provision for erosion control, taking into consideration local wind and icing conditions.

**Polishing storage ponds.**

- Storage ponds may have anywhere between 6 to 12 months of retention - even 2 years in the High Arctic - with BOD loadings ranging from 7 to 20 kg/ha•d.
- In Ontario, of about 245 lagoons the majority are operated without summer discharge because of receiving water requirements. The minimum retention time allowed is about 120 days.
- Alberta environment is looking for a significant improvement in storage pond effluent quality by requiring 12 months of nominal retention regardless of the time of discharge. An increase from the present requirement of 7 months.
- More information is needed on which to base the depth of storage ponds, especially regarding the presence or absence of a thermocline, ultraviolet light penetration, extent of intermixing, and natural disinfection.
- Berm size and length are a function of the active liquid volume to be stored, the amount of sludge to be accumulated on the bottom, the depth of ice and snow to be accommodated, and the net volume lost or gained from rainfall, infiltration, evaporation, and exfiltration.
- In Alberta, consideration is also being given to increasing the permissible maximum operating depth to 2.5 m from the present 2.4 m.
- The Ontario Ministry of the Environment allows up to 2.7 m deep storage, provided the BOD loading is less than 11.2 kg/ha•d. The depth requirement is based on considerable reduction in BOD prior to the storage cell.
- An increase in the mandatory depth of storage or polishing ponds by 1 meter, say, from 2.5 m to 3.5 m could not only mean savings in construction costs of 10 to 20 percent, but also have beneficial effects on nitrification and denitrification.

- When considering the depth of the storage cell beyond 1.7 m often the ability to use gravity flow to discharge the stored volume is lost. As soon as pumping is required, it is cheaper to buy the extra land and make the cell shallower which is commonly practised;
- Deepening storage ponds, as opposed to widening them to increase storage and decrease land requirements, may result in higher coliform counts in the effluent through decreased natural disinfection.

**3.6.4 Aerated Lagoons.** Aerated lagoons are classified into two groups: completely mixed aerobic aerated lagoons and incompletely mixed facultative aerated lagoons. The first group is characterized by substantial power input capable of keeping all the solids in suspension, satisfying oxygen demand, sustaining adequate dissolved oxygen (usually more than 1 mg/L) throughout the lagoon, and maintaining a completely mixed flow pattern.

In the second group the power input is sufficient only to satisfy the oxygen demand, but not adequate to keep all the solids in suspension. Some solids settle to the bottom and exert a benthal load on the system. The top layers exhibit an aerobic environment and the bottom layers an aerobic environment.

The difference between this and a facultative sewage lagoon addressed throughout the Workshop is the source of oxygen. The bacteria are the same, the mechanisms for conversion of soluble organics to cell mass and the chemical reactions are the same.

**Loadings and effluent quality.** The organic loading to facultative aerated lagoons expressed in mg BOD/L·d is about 1.0 to 1.5 orders of magnitude less than for extended-aeration, activated-sludge plants. Since solids sedimentation takes place in facultative aerated lagoons, effluent suspended solids quality may be in the 40- to 50-mg/L range. With loading rates of 19 to 29 mg BOD/L, unfiltered effluent $BOD_5$ may range from 25 to 80 mg/L, and filtered effluent $BOD_5$ from 20 to 40 mg/L.

The BOD loadings applied in practice to completely mixed aerated lagoons treating organic industrial wastes approach those of activated sludge systems. In terms of direct discharge the effluent BOD are quite unacceptable. Because no mechanism for suspended solids removal exists, these lagoons have very high effluent suspended solids from the solids going in and the biological solids being produced. Aerobic aerated lagoons must be followed by other cells for effluent polishing, especially to achieve suspended solids removal.

**Aeration devices.** A number of different devices are available to add supplemental oxygen into aerated lagoons. Whether they be facultative aerated lagoons where the mixing intensity is low, or aerobic aerated lagoons where the mixing intensity is high.

One group of low-intensity aeration devices supplies air from compressors to a series of slotted plastic tubes placed on the bottom of the lagoon at the desired spacing. One such system, known as "Air-Aqua", provides very fine diffusion of oxygen into the water, resulting in a very, very low intensity of mixing, and a reasonably high transfer efficiency of oxygen. Problems with air distribution have been encountered, because the small slots tend to plug up with carbonates. Operators have solved this problem by regular cleaning with anhydrous hydrogen chloride gas.

The "Air-Aqua" design provides plug flow-like facultative conditions in two in series-operated cells with decreasing air tube spacing for a total detention time of 28 days.

Another group is classed as static-tube aerators. Air distribution lines connected to air compressors come along the lagoon bottom to provide an air discharge at the bottom of the tube aerator. Lagoon water enters at the foot of this tube. The air and water are entrained as they rise up; oxygen transfer is enhanced by the mixing intensity in this tube.

When incorporated in a single-cell, 20-day retention lagoon, more of the required tube aerators are distributed at the inlet end to provide up to 5 $W/m^3$ of energy where the slotted tube systems provide only 1 $W/m^3$ of energy. With closer to complete-mix conditions at the inlet zone and little aeration at the end zone, better effluent quality is produced.

Earlier attempts in Ontario to use these devices in an activated sludge lagoon system provided sufficient oxygen for BOD removal but failed for want of sufficient mixing to keep the solids in suspension.

In designing aerated lagoons under northern conditions, Stanley and Associates call for at least two parallel cells followed by a 2-day, non-aerated pond to settle out suspended solids. The first section of the aerated pond providing a detention time of about six days is equipped with aerators at 1.64 to 2.64 $W/10^3L$ to approach as close as possible complete mix conditions. The remaining section of about 10 days of retention is also aerated but at a lower intensity, about 0.3 to 0.5 $W/10^3L$. The intense aeration at the head end of the system is to cope with the high BOD load and to keep the solids in suspension.

The firm prefers to use static-tube aerators because it has experienced problems of clogged orifices and broken tubing with the other type of subsurface aeration system first described. In winter, one can walk right up to the edge of the ice-free holes around with the static-tube aerators because it is quite thick all the way around. It stays open only right on top of the device. In fact, when it gets very cold, these will mount right over and there's just a little breathing hole on the top, but they nevertheless provide very effective aeration.

As already stated in Section 2.2.4, Alberta now has two systems under comparative study, where a small cell with 3 to 4 days of retention is completely mixed with high energy input at about 5 to 6 $W/m^3$ followed by 25 days of less intense aeration and 4 days of polishing without aeration. In one, static-tube aerators are being used; in the other, diffused air tubing. Both were reported to be operating quite well.

There are a number of other subsurface devices. "Pemberthy", for example, has a pump driven air-water mixing device that is quite effective. It sits on the bottom of a lagoon and provides oxygen. Some devices permit oxygenation even with a complete ice cover.

Another possibility is the floating mechanical aerator. From the splash pattern formed, reasonable aeration occurs because of the entrainment of the air and oxygen. These floating devices are almost always high-speed aerators. They generally run at the motor speed of 1700 rpm. They provide intermediate mixing levels; they don't mix very deeply. Probably 1.5 to 2.1 m is the maximum depth of mixing, unless you can get a good draft tube on them. These are considered to be intermediate intense mixing devices. They have not been successfully applied to year-round cold-climate installations being subject to differential loading and complete freezeup.

In Manitoba, one 14-day retention lagoon has the mechanical aerator placed directly over the influent pipe to prevent freezing by taking advantage of the heat in the incoming sewage. During the winter this lagoon achieved 70 percent BOD removal without odour. However, from the year-round BOD removal data, it was not possible to tell when the aerator was or was not in service.

Bridge-mounted mechanical units are generally lower-speed devices; they operate at around 60 rpm instead of 1700 rpm for floating aerators. They are not always connected to the shore with a walkway. These devices can effectively mix up to 5 m in water depth and even deeper if they're provided with a longer shaft and a lower mixer. These devices, in fact, provide complete solids suspension in a lagoon. They would be used in an aerobic aerated lagoon.

Bridge-mounted aerators in cold-climates are difficult to maintain in operation when encased in ice.

**Short circuiting.** For a true completely mixed lagoon, dye should appear in the effluent very shortly after having been added to the influent. To determine whether short circuiting had occurred one must relate the mean residence time to the theoretical detention time. It is how the dye decays with time that is important. If, for example, the mean residence time is 7 days in a 30-day pond then some short circuiting is occurring.

The flow characteristics are influenced by the type of aeration equipment. In designing for plug flow, density currents may play a major adverse role whether along the surface or along the bottom, thus resulting in short circuiting. The actual detention time is also influenced by the inlet and outlet design, the lagoon geometry, and any baffling which may be provided.

The flow characteristics are also influenced by the type of aeration equipment. Subsurface aeration usually provides better plug flow conditions with fewer problems during the wintertime due to icing. Experience indicates that there is no such thing as true plug flow in aerated lagoons. They operate somewhere between plug flow and plug flow as graphed by Dr. Thirumurthi (Appendix D-4).

**Dissolved oxygen under ice cover.** In Quebec, the University of Sherbrooke has measured 4 to 5 mg/L to saturation valves under ice during the winter months using membrane-type dissolved oxygen meters.

With a deeper ice cover of about 2 m, oxygen can be supplied by means of a submerged type of aerator. It is not necessary to break the ice cover. The air will find a way out through the ice. Ice movement from air pressure during winter and upon spring breakup must be considered in designing the anchors for the diffused air distribution piping to prevent pipe breakage.

Air bubbling systems may be used to reduce ice formation on water impoundments where heat is provided from the underlying deeper waters. This heat cannot be counted on in normal municipal lagoons. Studies in Manitoba on impounded waters, dugout farm supplies and dugouts serving municipalities show uniform winter temperatures of 4°C from top to bottom.

**Mathematical model coefficients.** An edited version of an earlier paper prepared by Jean Marc Jalbert on the theory and design practice of Municipal Wastewater Management, Ministry of the Environment, Government of Quebec, discusses aerated facultative lagoon design and the work done under contract by École Polytechnique to determine working values of the coefficients K and $\theta$ used in the design method.

Although good comparative results were obtained, the École Polytechnique concluded that the Warburg respirometer method is more reliable than the conventional BOD method for determining the values of K and θ in the laboratory.

Field data obtained at one aerated lagoon site in Quebec over three seasons failed to give a good correlation between the laboratory values and the actual calculated values for K and θ. Although a considerable amount of data was obtained (see Table 9), additional studies at more optimal sites are required to verify the value of the coefficients used in the design method proposed in the technical notes.

From the literature, there appears to be a lot of confusion about evaluating the values of K. Different people propose different values.

There is a retardent effect to be accounted for. If the same wastewater goes to three aerated lagoons of varying detention time, the value of K is going to be highest in the lagoon with the shortest detention time because it is easiest to remove the initial BOD. The longest detention lagoon will have the lowest K value. In other words, if all the parameters are kept constant, with the same sewage coming in, a plot of the retention time versus K will give the highest values at the beginning and the lower values later on; i.e., K increases as the organic load increases.

In his work "Design Guidelines For Incompletely Mixed Aerated Lagoons" (Canadian Journal of Civil Engineering V1, No. 1, pp. 27-35. 1980), Thirumurthi proposed design guidelines for facultative aerated lagoons (Group 2) based on laboratory-model studies of three 53.5-cm deep tanks of different sizes and shapes subject to various loading conditions, detention periods, and compressed air mixing/aeration rates. Steady-state conditions were established before the K values were determined.

The three test runs were preceded by preliminary tracer studies, which were designed to estimate the magnitude of the dispersion index (d) for the three tanks at various air flow rates. The tracer studies showed that as the air flow rate increased, the magnitude of the dispersion index (d) increased. Tanks with higher length-width ratios are usually characterized by lower d values (i.e. closer to plug flow). The air required to keep all solids in suspension was much more than that required to satisfy the BOD.

Theoretically, the values of K at 20°C which were computed from the Wehner and Wilhelm equation should be the same for all three tanks of the same test run. The experimental errors or inaccuracies were considered to be insignificant therefore substantiating the validity of the Wehner and Wilhelm equation and the Thirumurthi chart for designing incompletely mixed aerated lagoons.

The mean values of $K_{20}$ for each test run varied from a high of 0.287/d to a low of 0.232/d, exhibiting a retardant effect as the detention time increases.

A universal or standard design coefficient ($K_s$) is used as a design tool to compute the volume of an aerated lagoon, subject to a set of arbitrarily chosen factors. Thirumurthi uses a liquid temperature of 20°C and an organic load of 20 $g/m^3 \cdot d$ as the standards corresponding to $K_s$.

The straight line plot of $K_{20}$ as a function of log L (the organic load) and the computation of the slope indicate the following relationship

$$\log_{10} 20 - \log_{10} L_l = 8.5 (K_s - K_{20}) \tag{3-1}$$

where $K_{20}$ is the first-order BOD removal coefficient at the organic load $L_l$ in $g/m^3 \cdot d$ at 20°C.

Equation 3-1 is used to correct $K_s$ for any field loading condition. The K values determined in the laboratory are usually slightly higher than those determined from field measurements.

The mean value of $K_s$ from this study, shown in Table 3-6 is 0.29/d, which is being proposed as the key design factor for facultative aerated lagoons treating municipal (domestic) wastewaters. In 1979, Thirumurthi had recommended a $K_s$ value of 0.50 for completely mixed aerobic aerated lagoons.

TABLE 9 INTERPRETATION OF RESULTS FROM MATHEMATICAL MODELLING

| Tank | Dispersion index (d) | BOD remaining ($C_e/C_i$) | Value of K at 20°C for each tank ($K_{20}$) | Test run | Mean value of K at 20°C for each test run | Organic load, $L_l$ ($g/m^3 \cdot d$) | Standard K for each test run (corrected for organic load) ($K_s$) |
|---|---|---|---|---|---|---|---|
| P1 | 5.6 | 0.247 | 0.281 | P | 0.287 | 19.8 | 0.288 |
| P2 | 4.6 | 0.237 | 0.289 | P | 0.287 | 19.8 | 0.288 |
| P3 | 3.6 | 0.227 | 0.292 | P | 0.287 | 19.8 | 0.288 |
| Q1 | 3.0 | 0.095 | 0.235 | Q | 0.232 | 6.7 | 0.288 |
| Q2 | 1.9 | 0.085 | 0.232 | Q | 0.232 | 6.7 | 0.288 |
| Q3 | 1.3 | 0.080 | 0.230 | Q | 0.232 | 6.7 | 0.288 |
| R1 | 4.5 | 0.143 | 0.250 | R | 0.250 | 9.8 | 0.287 |
| R2 | 3.2 | 0.138 | 0.248 | R | 0.250 | 9.8 | 0.287 |
| R3 | 2.0 | 0.122 | 0.252 | R | 0.250 | 9.8 | 0.287 |

Note: Mean value of K for three test runs = 0.288.

The standard BOD removal coefficient ($K_s$) must be corrected for the actual liquid temperature (T) by using in the equation the commonly known temperature correction coefficient (θ) which normally varies from 1.030 to 1.055.

$$K = K_{s\theta}(T-20) \tag{3-2}$$

Applying this method to aerated lagoon design in Nova Scotia and P.E.I., Dr. Thirumurthi uses $K_s = K_{20} = 0.3$ per day and a temperature correction factor ($\theta = 1.035$). In winter, when the liquid temperature is 2° or 3°C, BOD removals of about 80 percent are obtained. In summer, at about 15°C, the BOD removal increases to 90 percent. One facultative aerated lagoon designed to serve two small communities in P.E.I., using these parameters, measured 88 percent BOD removal in the summer and about 83 percent in the winter. The daily BOD loading with normal municipal wastewater was 8 g/$m^3$ of lagoon volume. The retention time ranged between 20 and 28 days.

At the workshop, doubts were expressed about the validity of trying to generate K values from both the Warburg respirometer and BOD bottle techniques. The results are influenced by the way the tests are run. When applied even on a pilot scale, the level of intensity of mixing and the amount of solids kept in suspension influence the value of K obtained. To simulate an event in a lagoon, one must simulate both the biological and mixing regimes. This is difficult to accomplish in the laboratory. With the Warburg respirometer, increased agitation produces higher K rates. Relative K rates can be determined as long as the technique used remains the same, but it is not realistic to apply someone else's results without knowing exactly the method used.

In unusual situations, such as unknown industrial wastewater inputs, it is essential to do good laboratory work to determine a working range of K values. Otherwise it is more prudent to establish a reasonable design based on experience gained from successful installations rather than adjust assumed reaction rate coefficients and correction factors until a sensible design is reached.

**Phosphorus removal.** For about 1-1/2 years, the Department of Civil Engineering, University of Sherbrooke, has been doing some work in the laboratory and at a facultative aerated lagoon in the Eastern Townships of Quebec on phosphorus removal. The lagoon built in two cells is equipped with two surface aerators which are removed as winter approaches (mid-November). The aerators have been operated in this manner for 7 years without problems.

The influent is quite weak due to infiltration; BOD and suspended solids concentrations are in the order of 70 to 80 mg/L. The total influent phosphorus concentration is 4.27 mg/L in the summer and 4.17 mg/L in the winter. The effluent concentration without chemical treatment is about 3 to 4 mg/L.

Three coagulants have been used in an effort to get an effluent with about 1 mg/L of total phosphorus by trying three coagulants: alum, ferric chloride, and lime. Alum seems to be the best coagulant of the three for this application.

Results obtained from the above studies lead to the following conclusions:

- A linear relationship exists between phosphorus removal and coagulant dosage which can be described by a simple equation $\ln (Pr/Po) = K_p \cdot M/Po$ where Pr and Po are respectively the residual and initial phosphorus concentrations in mg/L, $K_p$ is the proportionality constant and M is the coagulant dosage in mg/L.
- Phosphorus removal at the primary level shows that for a 95-percent reduction of total phosphorus, an Al/Po ratio of 2.55 is required; for a 99-percent removal at ratio increases to 3.75 provided other conditions remain the same. The operating pH is 7.80. When pH adjustment is made to 6.50 then the Al/Po ratio drastically is reduced to between 1.50 and 1.85.
- Phosphorus removal at the secondary level (aeration tank) is also efficient but uneconomic in terms of dosage of chemical and operation. For example, at the primary level an Al/Po of 1.50 was sufficient to remove 97 percent of total phosphorus. To achieve the same degree of removal at the secondary level an Al/Po ratio of 4.50 had to be attained.
- The filterable orthophosphate fraction precipitates at an Al/Po of 0.70 and higher. Below this ratio the phosphorus removal is only that of polyphosphates.
- Our results also show that the coagulation process was not adversely affected by temperature variations. Factors such as coagulant dosage, BOD and SS removals remained essentially the same during winter and summer seasons. In case of ferric chloride at the primary level, of optimum pH was found to be 4.75.
- At this pH, the Al/Po ratios for 95 and 99 percent total phosphorus removal were 6.80 and 10.20 respectively. Ferric chloride is much more difficult than alum. However, for low concentrations of filterable phosphorus (FP), in the order of 1.5 to 3.0 mg/L, ferric chloride is better coagulant than alum.
- Addition of a polyelectrolyte at a dosage of 0.30 mg/L results in a much better and easily settlable floc in case of $FeCl_3$. Lime is an effective coagulant in wastewater

treatment. However, its use is hampered by its large dosage to achieve desired phosphorus removal. In our study it was found that for 50-percent removal of total phosphorus the coagulant dosage was over 500 mg/L; the resulting pH was 11.50. Seasonal variations of phosphate species in wastewater are being studied in existing aerated lagoons. Results show that the average total orthophosphate (TOP) concentration in the influent varies little between summer and winter seasons (i.e. <1 percent). However its concentration in summer effluent is 34 percent higher than in winter.

- The TOP/TP ratios for winter and summer indicate an increase of 32-percent in summer over winter. This is probably due to bacterial hydrolysis of polyphosphates into orthophosphates in warm temperatures. Further studies are needed to confirm these observations with other lagoons operating under similar conditions.

### 3.6.5 Operational and Maintenance Considerations.

**Effluent control structures.** A common type of liquid level control structure incorporates a series of stop logs for varing the operating depth. The logs tend to swell and jam in their retaining grooves making them difficult to remove. Once removed and later replaced they may no longer be watertight. Removed logs not in use have been known to disappear from the site or worse, end up in the outfall sewer. The effluent control manhole should be placed to one side of the berm centre line so that vehicle access is not impeded. Alternate designs to stop logs include the use valved overflow and drain pipes. One configuration calls for an upturned-T piping arrangement.

Our approach is generally to stay away from stop logs. There's some difficulty in handling stop logs. What we generally like to see for an effluent control manhole is first of all not to put it in the centre of the berm. Put it on one side to permit vehicle access around the structure and also have generally an upturned pipe to act as an overflow. This upturned pipe would have a T. In the manhole would be a valve with a stem going up to the top and this valve can also be used as a drain valve for draining lagoon systems.

Configurations must permit access to control structures and sampling points.

**Erosion protection.** There have been a number of instances where high winds have created considerable damage to berms; and berm have failed because of the wind action on the shoreline. The approach in the past has quite often been to sow grass on the berms, hoping that this provides sufficient protection. Even wind of little force may cause wave-induced erosion and over the years cause deterioration of the windward berms.

Riprapping and log booms have also been used to curtail erosion, but better approaches are needed.

**Seepage prevention.** Alberta Environment has developed a design manual, "Design and Construction of Liners for Municipal Wastewater Stabilization Ponds" a summary of which will be included in its next standards revision. It has found that seepage is a major problem with operating lagoons. The requirements for the geotechnical site investigation and liner design/installation must be detailed and rigorous.

# APPENDIX A

## WORKSHOP PROGRAM

# COLD CLIMATE SEWAGE LAGOONS WORKSHOP
FORT GARRY HOTEL, WINNIPEG, MANITOBA
JUNE 5-7, 1985

Sponsored by:

Technical Services Branch, EC
Technical Services and Contracts Branch, INAC
Medical Services Branch, HWC

Wednesday, June 5 **"WHERE ARE WE WITH LAGOONS?"**

Chairman's Opening Remarks - Dave Hay

| "Needs and Expectations" | Sector Representatives |
|---|---|
| Environment | Dave Hay |
| Public Health | Bert Caine |
| Owners/Operators | Bob Holloway/Barry MacBride |
| Consultants | Pat Given |
| Universities | Art Sparling/Eric Davis |

U.S.A. Perspective - Al Townshend

CANADA

"A Critical Evaluation of the Operation and Performance of Lagoons in Cold Climates" - Dan Smith, Professor of Civil Engineering, U. of Alberta, Edmonton

Tabling of Data from Canadian Lagoon Studies - J.M. Jalbert, J. Neil, G. Rupke, Rangit Soniassy. (See Appendix E)

## "LAGOON THEORY"

| | |
|---|---|
| Chairman | Dan Smith |
| Recorder/Summator | Dave Green |
| | Discussors |
| Climatical/Biological/Physical-Chemical and Geotechnical Considerations | John Neil/Durga Prasad/Ross Bulley |
| Number of Cells/Configuration and Discharge Control | Subba Narasiah/Alvin Beier |

Thursday, June 6

## "LAGOON DESIGN AND OPERATION"

| | |
|---|---|
| Chairman | Bob Dawson |
| Recorder/Summator | Ross Holden |
| | Discussors |
| Site Selection | Pat Given/Yves Lord |
| Current Design Models & Research Needs | Dan Thirumurthi |
| Process Design | Ron Kent<br>Yves Dubuc<br>Pat Given<br>Pat Lang |
| Construction | Hank Johnston |
| Operation | Gerry Rupke/Paul Klaamas<br>Yves Dubuc/Mike Cassiram |

## "UPGRADING LAGOON SYSTEMS"

| | |
|---|---|
| Chairman | Neil Jacobsen |
| Recorder/Summator | Ron Zaloum |
| | Discussors |
| Overview of Ontario Experience | Steve Black |
| Nutrient Removal by Duckweed | Ross Bulley |
| Harvesting Biological Production | John Neil |
| Natural Wetlands Treatment | Andy Bemister |
| Peat Bog Wetlands | Yves Dubuc |

## "AERATED LAGOONS"

| | |
|---|---|
| Chairman | Ron Zaloum |
| Recorder | Neils Jacobsen |
| | Discussors |
| Aerated Lagoon Design in Quebec | Jean Marc Jalbert |
| Oxygen Input and Performance | Gerry Rupke |
| Phosphorus Removal | Subba Narasiah |

## "WHERE DO WE GO FROM HERE?"
## (Summary Panel on Lagoon Theory and Practice)

| | |
|---|---|
| Chairman | John Benner |
| Recorder/Summator | Gerry Rupke |
| Lagoon Theory | Dan Smith |
| Design and Operation | Bob Dawson |
| Upgrading Lagoon Systems | Neils Jacobsen |
| Aerated Lagoons | Ron Zaloum |

## Friday, June 7 **"GETTING ON WITH IT"**

| | |
|---|---|
| Chairman | Bruce Jank |
| Recorder/Summator | Steve Black |

| | Leader |
|---|---|
| Concensus on Research Topics | Dan Smith |
| Ranking Identified Research Topics | Bruce Jank |
| Implementation Plans Closing Remarks | Bruce Jank |
| Government | Mike Van Den Bosch |
| Consultants | John Neil/Bob Dawson |
| Universities | Eric Davis |

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# APPENDIX C

## SUMMARY OF IDENTIFIED RESEARCH NEEDS BY TOPICS AREA AND PRIORITY

## SUMMARY OF IDENTIFIED RESEARCH NEEDS BY TOPIC AREA AND PRIORITY

| Topic Area | Project Number | Project Description | Priority Interest 0 (Nil) to 10 (High) |
|---|---|---|---|
| 1.0 State-of-the-Art | | | |
| | 26 | Performance and effluent quality from seasonal discharges. | 7 |
| | 25 | Seasonal influences on continuous discharge systems. | 4 |
| | 41 | Compile cost information on lagoon systems (capital, O & M and monitoring). | 4 |
| | 34 | Data from operating systems on sludge and sludge disposal experience accumulation rates. | 2 |
| | 27 | Survey of existing operational lagoons to document problems, innovations and successes. | 10 |
| | 17 | Investigate performance of liners at existing lagoons. | 1 |
| | 21 | Evaluate newly developed liner and sealing methods and materials | 1 |
| | - | Critical evaluation/analysis of variation of provincial lagoon design/loading criteria | - |
| 2.0 Environmental/ Health Concerns | 62 | Identification of the health problems related to the use of lagoons. | 5 |
| 2.1 Groundwater/Soil Contamination | 20 | Seepage allowances for embankments and lagoon bottoms. | 3 |
| | 63 | Seepage and leakage control. | 3 |
| | 32 | Nitrogen removal in lagoon systems. (See 5.1) | 2 |

SUMMARY OF IDENTIFIED RESEARCH NEEDS BY TOPIC AREA AND PRIORITY (Cont'd)

| Topic Area | Project Number | Project Description | Priority Interest |
|---|---|---|---|
| 2.2 Effluent/Sludge Disposal | 39 | Use of wetlands or other aquatic components as part of the overall lagoon treatment process. (See 4.2) | 5 |
| | 40 | Use of natural ponds or lakes for lagoon treatment. (See 4.2) | 4 |
| | 37 | Criteria for sludge disposal in the arctic and subarctic. | 1 |
| 2.3 Pathogens/ Disinfection | 46 | Evaluation of indicator organisms as representative of the presence of pathogens. (See 3.0) | 7 |
| | 56 | Design criteria to optimize pathogen removal. (See 5.1) | 6 |
| | 57 | Study of R factor bacteria survival and reduction. (See 5.1) | 4 |
| | 29 | Pathogen reduction through natural die-off. (See 5.1) | 3 |
| | 31 | Ultraviolet disinfection. | 2 |
| | 30 | Ozone disinfection. | 0 |
| 2.4 Odour & Aerosols | 33 | Odor control or prevention. | 7 |
| | 48 | Effect of anaerobic cell size on the production of odor. | 3 |
| | 64 | Aerosols generated at aerated lagoons. | 1 |
| 3.0 Operation and Maintenance and Process Control | 44 | Develop monitoring standards. | 9 |
| | 46 | Evaluation of indicator organisms as representative of the presence of pathogens. (See 2.3) | 7 |
| | 45 | Develop operating standards. | 5 |
| | 65 | Standardized training package. | 3 |

SUMMARY OF IDENTIFIED RESEARCH NEEDS BY TOPIC AREA AND PRIORITY (Cont'd)

| | Topic Area | Project Number | Project Description | Priority Interest |
|---|---|---|---|---|
| 3.0 | Operation and Maintenance and Process Control (Cont'd) | 61 | Proper statistical analysis procedures. | 3 |
| | | 54 | Development of analytical standards suitable for lagoons. (BOD, TSS, TOD) (microbiological). | 2 |
| | | - | Practical methods for controlling growth of emergent vegetation. | - |
| 4.0 | Lagoon Upgrading Technologies | 10 | Conversion of existing lagoons to partial mix units. | 2 |
| 4.1 | Aerated Lagoons | 8 | The use of small complete mix aerated cell followed by polishing cells. (See 5.4) | 2 |
| 4.2 | Land/Lake Application | 39 | Use of wetlands or other aquatic components as part of the overall lagoon treatment process. (See 2.2) | 5 |
| | | 40 | Use of natural ponds or lakes for lagoon treatment. (See 2.2) | 4 |
| 4.3 | Chemical/Physical | 28 | Reduction of effluent suspended solids with biological and chemical means, auto-flocculation, filtration and microscreens. (See 5.1) | 1 |
| 5.0 | Lagoon Theory/ Design | | | |
| 5.1 | Biology | 1 | Define the biokinetics in a lagoon under an ice cover. | 6 |
| | | 56 | Design criteria to optimize pathogen removal. (See 2.3) | 6 |
| | | 57 | Study of R factor bacteria survival and reduction. (See 2.3) | 4 |
| | | 29 | Pathogen reduction through natural die-off. (See 2.3) | 3 |

SUMMARY OF IDENTIFIED RESEARCH NEEDS BY TOPIC AREA AND PRIORITY (Cont'd)

| Topic Area | Project Number | Project Description | Priority Interest |
|---|---|---|---|
| 5.1 Biology (Cont'd) | 2 | Evaluate the role of psychrophillic organisms in lagoons and their relationship to loading | 3 |
| | 43 | Effect of ratio of soluble to total/BOD | 3 |
| | 58 | Design of anaerobic cells. | 3 |
| | 32 | Nitrogen removal in lagoon systems. (See 6.1) | 2 |
| | 50 | Phosphorus removal in lagoon systems. | 2 |
| | 55 | Liminological investigation of lagoons to improve understanding of the dynamics. | 2 |
| | 6 | Effect of pH (extreme values) on lagoon performance. | 1 |
| | 7 | Effect of high dissolved solids on performance. | 1 |
| | 28 | Reduction of effluent suspended solids by autoflocculation. (See 4.3) | 1 |
| | - | Effect of temperature on organisms other than bacteria | - |
| 5.2 Physical/ Mechanical | 3 | Define rational design procedures for aerated facultative lagoons. | 4 |
| | 23 | Evaluate long term performance of aeration devices in existing lagoons. | 4 |
| | 4 | Define the relationship between organic load and oxygen requirements for aerated lagoons. | 1 |
| | 51 | Alternative sources of energy for aeration. | 1 |

SUMMARY OF IDENTIFIED RESEARCH NEEDS BY TOPIC AREA AND PRIORITY (Cont'd)

| Topic Area | Project Number | Project Description | Priority Interest |
|---|---|---|---|
| 5.3 Waste Descriptor | 53 | Effect of various small industries on community lagoons | 4 |
| | 42 | Develop degradable honey bag to permit direct disposal to lagoons. | 0 |
| 5.4 Configuration | 49 | Design criteria for small and temporary lagoons. | 6 |
| | 14 | Best shape/configuration depth for lagoon cells. | 5 |
| | 5 | Best design procedures for cold climates, continuous discharge systems. | 4 |
| | 52 | Lagoon size optimization. | 3 |
| | 12 | Optimum number of cells for either seasonal discharge or continuous flow. | 3 |
| | 9 | The use of small anaerobic cells followed by polishing cells. | 1 |
| | 8 | The use of small complete mix aerated cell followed by polishing cells. (See 4.1) | 1 |
| 5.5 Hydraulic Regime | 11 | Determine actual hydraulic detention time in operating systems considering precipitation, evaporation, and seepage. | 3 |
| | 13 | Relative detention times in multiple cell systems. | 2 |
| | 15 | Best location for inlet and outlet structures be located. | 1 |
| | 16 | Develop baffling systems to insure plug flow, but which resist ice forces. | 1 |
| | 59 | Low cost erosion protection techniques. | 1 |
| | 18 | Design criteria of inlet and outlet structures to eliminate ice problems. | 0 |

SUMMARY OF IDENTIFIED RESEARCH NEEDS BY TOPIC AREA AND PRIORITY (Cont'd)

| Topic Area | Project Number | Project Description | Priority Interest |
|---|---|---|---|
| 5.6 Sludge Accumulation | 36 | Criteria and methods for sludge removal. | 4 |
|  | 35 | Criteria for determining when it is necessary to remove sludge. | 3 |
|  | 38 | In-situ consolidation of sludge (chemical or biological means). | 1 |
|  | 60 | Critical analysis of sludge digestion on facultative lagoon performance. | 3 |
| 5.7 Process Modelling | 47 | Dynamic model of lagoon process. | 2 |
| 6.0 Planning/Site Selection Criteria | 22 | Geotechnical criteria for lagoon site selection in permafrost areas. | 3 |
| 7.0 Construction | 19 | Criteria for embankment construction. | 1 |
|  | 24 | Mixing sludge with bottom soils during construction to induce rapid sealing. | 1 |

# APPENDIX D

# CONTRIBUTIONS BY PRESENTERS AND DISCUSSORS AT THE COLD-CLIMATE LAGOONS WORKSHOP; WINNIPEG, MANITOBA JUNE 5-7, 1985

D-1 Lagoons in the City of Winnipeg
D-2 Lagoon Treatment Performance in Alberta
D-3 Summary of Design Models for Sewage Lagoons
D-4 Sewage Lagoon Design Criteria
D-5 Operator Training Concept

## APPENDIX D-1

## LAGOONS IN THE CITY OF WINNIPEG

Prepared by B. MacBride, P. Eng.

### 1. EXPERIENCE

The City of Winnipeg has operated a system of facultative lagoons since 1964. In addition, the City installed and evaluated three aerated lagoon systems on an experimental basis for two years.

### 2. FACULTATIVE LAGOONS - WEST END WATER POLLUTION CONTROL CENTRE

#### 2.1 Description

3 Primary cells at 18.2 ha = 54.6 ha
2 Secondary cells at 25.3 ha = 50.6 ha
105.2 ha

#### 2.2 Capacity

Summer 15.3 MLD based on primary cell loading of 56 kg $ha^{-1}d^{-1}$
Winter 6.0 MLD based on 1/2 P+S - 196-day storage
Note that the facility also includes extended aeration mechanical plant with capacity approximately 25 MLD.

#### 2.3 Operation

Primary cells normally operated in series but parallel operation is used when first primary is overloaded.
Secondary cells operated in parallel.
All cell levels are lowered in the fall to allow for total retention in winter.
One secondary cell is used in winter as cooling pond for mechanical treatment plant.

#### 2.4 Performance

| | Influent* | Effluent | % Removal* |
|---|---|---|---|
| SS mg/L | 183 | 39 | 79 |
| $BOD_5$ mg/L | 200 | 37 | 82 |
| TOC mg/L | 140 | 45 | 68 |

* Influent samples taken in mechanical plant after screening (hydrasieves). Therefore sewage to lagoons would be of a higher strength and thus the removal rates are understated.

### 2.5 Issues

Erosion is an operational problem.
Odour during spring breakup is a political problem in terms of complaints and pressure to develop in the vicinity of the lagoons.

## 3. AERATED LAGOONS

### 3.1 Description

Three 2.3 MLD aerated lagoons were tested during 1968 and 1969.
The three aeration forms were:

1. Air Aqua, 30-day retention;
2. Mechanical Surface Aerators, 20-day retention;
3. Air Gun, 20-day retention.

### 3.2 Performance

Results (21-month average)

Influent SS 188 mg/L
$BOD_5$ 175 mg/L

| Effluent | $BOD_5$ (mg/L) | SS (mg/L) |
|---|---|---|
| 1. Air Aqua | 37 | 34 |
| 2. Surface Aerator | 38 | 39 |
| 3. Air Gun | 34 | 34 |

Sludge Accumulation

.08 to .11 kg $cap^{-1}day^{-1}$

### 3.3 Problems

Ice on surface aerators
Rags fouling air guns

### 3.4 Dye Studies

Air Aqua - Dye in effluent 9 minutes after introduction
- Maximum concentration at T = 9 days

Air Gun - Surface Aerator
- Maximum concentration at 24 hours

# APPENDIX D-2

## LAGOON TREATMENT PERFORMANCE IN ALBERTA

by Environment Alberta

Sewage lagoons (wastewater stabilization ponds) are and have been the most common form of sewage treatment in Alberta. In 1984 a total of 363 communities were employing some form of sewage treatment; of this total, about 297 communities were using lagoon treatment. Sixty-five percent of the lagoon systems utilize the anaerobic-facultative type treatment with the remainder using single or multiple facultative cells. Alberta's present standard for lagoon construction is two or four anaerobic cells (where applicable), one two months' retention. Presently about 60% of the lagoon systems provide twelve month's storage.

An evaluation of lagoon effluent quality, conducted on samples collected throughout the 1978 to 1983 period, revealed the following significant findings:

(a) All lagoons which provide twelve months of detention produced better quality effluents than those with 6-month detention.

(b) Fall discharges produce better quality effluents than spring discharges regardless of detention times.

(c) May discharge periods showed significant improvement in quality over April discharge periods (i.e., after the ice cover had disappeared and pond turnover is complete).

(d) Lagoon systems with the configuration of four anaerobic cells and two or more facultative cells generally provided the best quality effluents for both spring and fall drainage periods.

(e) Lagoon depths of less than 2 m provide better treatment than those having depths of two metres and more. Effluents from storage ponds capable of twelve months' detention appeared to be unaffected by the depth of the final holding pond.

(f) When continuous overflow is allowed from April to September, the effluent is improved. Lower organic nutrient loadings and volumes are released than associated with the volumes and quality of spring drainage.

The findings shown above and the following supportive tables should only be viewed as "indicative trends" due to the many variables involved. Some of these variables include differences in the size and type of lagoon configurations, influent quality and flows, state of repair, time span of sampling, sampling errors, population differences, number of results used in determining averages, and many others which can have an effect on the lagoon effluent quality.

TABLE D-1 LAGOON EFFLUENT QUALITY FOR ONCE-A-YEAR DISCHARGE

| Parameter (mg/L) | Spring | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | Average |
| BOD | 52 | 26 | 23 | 12 | 28 | 32 | 29 |
| NFR | 16 | 35 | 27 | 34 | 49 | 27 | 31 |
| COD | 139 | 157 | 150 | 121 | 94 | 122 | 130 |
| N-TK | 24.0 | 24.3 | 18.0 | 12.2 | 15.1 | 13.6 | 17.8 |
| P-T | 9.3 | 5.5 | 5.1 | 2.6 | 3.1 | 4.1 | 4.9 |
| $NH_3$-N | 20.4 | 14.9 | 13.7 | 6.2 | 12.9 | 10.6 | 13.1 |
| No. of Analyses | 5 | 3 | 7 | 8 | 10 | 12 | 45 |

| Parameter (mg/L) | Fall | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | Average |
| BOD | 7 | 10 | 6 | 6 | 9 | 10 | 8 |
| NFR | 24 | 16 | 4 | 29 | 35 | 25 | 22 |
| COD | 65 | 92 | 81 | 12 | 101 | 67 | 70 |
| N-TK | 7.1 | 3.7 | 4.1 | 1.0 | 8.5 | 5.7 | 5.0 |
| P-T | 5.5 | 2.5 | 1.1 | 0.7 | 3.3 | 1.9 | 2.5 |
| $NH_3$-N | 4.6 | 0.9 | 0.4 | 0.28 | 4.8 | 2.6 | 2.3 |
| No. of Analyses | 9 | 2 | 2 | 2 | 15 | 19 | 49 |

TABLE D-2 LAGOON EFFLUENT QUALITY FOR TWICE-A-YEAR DISCHARGE

| Parameter (mg/L) | Spring | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | Average |
| BOD | 106 | 31 | 84 | 39 | 50 | 60 | 62 |
| NFR | 30 | 40 | 27 | 28 | 49 | 28 | 34 |
| COD | 195 | 166 | 176 | 146 | 148 | 149 | 163 |
| N-TK | 25.7 | 17.4 | 30 | 22.2 | 28.1 | 23.9 | 24.5 |
| P-T | 9.2 | 5.1 | 7.8 | 7.0 | 6.6 | 7.1 | 7.1 |
| $NH_3$-N | 23.8 | 11.7 | 23 | 17.0 | 22.0 | 22.4 | 20.0 |
| No. of Analyses | 24 | 11 | 14 | 25 | 17 | 26 | 117 |

| Parameter (mg/L) | Fall | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | Average |
| BOD | 20 | 20 | 15 | 18 | 11 | 15 | 16 |
| NFR | 35 | 23 | 19 | 38 | 35 | 30 | 30 |
| COD | 95 | 153 | 125 | 106 | 80 | 95 | 109 |
| N-TK | 10.4 | 10.2 | 14 | 7.9 | 8.5 | 10.7 | 10.2 |
| P-T | 4.6 | 5.2 | 4.4 | 3.5 | 3.5 | 3.7 | 4.1 |
| $NH_3$-N | 5.3 | 6.1 | 8.8 | 4.6 | 5.6 | 5.6 | 6.0 |
| No. of Analyses | 30 | 7 | 10 | 19 | 40 | 47 | 153 |

TABLE D-3 1983 SPRING DISCHARGES

| Parameter (mg/L) | 6-Month Storage |  | 12-Month Storage |  |
|---|---|---|---|---|
|  | April | May | April | May |
| BOD | 74 | 38 | 42 | 18 |
| NFR | 27 | 31 | 34 | 16 |
| COD | 163 | 128 | 145 | 85 |
| N-TK | 25.1 | 22.2 | 16.6 | 8.8 |
| P-T | 7.3 | 6.9 | 5.4 | 2.2 |
| $NH_3$-N | 21.9 | 15.4 | 13.7 | 5.6 |
| No. of Analyses | 16 | 10 | 7 | 5 |

TABLE D-4 LAGOON CONFIGURATION VS EFFLUENT QUALITY FOR ONCE-A-YEAR FALL DISCHARGE

| Lagoon Configuration | Effluent Quality (mg/L) |  |  |  |  |  | Total Number of Samples |
|---|---|---|---|---|---|---|---|
|  | BOD | NFR | COD | N-TK | P-T | $NH_3$-N |  |
| 1L or more | 14 | 55 | 135 | 13.4 | 4.9 | 8.6 | 6 |
| 2S 1L | 16 | 24 | 72 | 4.5 | 1.3 | 0.8 | 3 |
| 2S 2L or more | 8 | 24 | 61 | 6.1 | 2.1 | 3.2 | 13 |
| 4S 1L | 28 | 88 | 156 | 13.0 | 4.0 | 5.5 | 1 |
| 4S 2L or more | 7 | 18 | 71 | 5.2 | 2.3 | 2.7 | 20 |

## TABLE D-5 LAGOON CONFIGURATION VS EFFLUENT QUALITY FOR ONCE-A-YEAR SPRING DISCHARGE

| Lagoon Configuration | Effluent Quality (mg/L) | | | | | | Total Number of Samples |
|---|---|---|---|---|---|---|---|
| | BOD | NFR | COD | N-TK | P-T | $NH_3$-N | |
| 1L or more | 40 | 49 | 138 | 20.3 | 4.8 | 13.2 | 12 |
| 2S 1L | - | - | - | - | - | - | - |
| 2S 2L or more | 31 | 19 | 99 | 10.6 | 2.9 | 8.2 | 4 |
| 4S 1L | - | - | - | - | - | - | - |
| 4S 2L or more | 18 | 26 | 114 | 13.7 | 3.8 | 9.8 | 26 |

Note: "S" - indicates anaerobic cells with short detention (2 to 5 days)
"L" - indicates facultative cell with long detention (365 days)

## TABLE D-6 LAGOON CONFIGURATION vs. EFFLUENT QUALITY FOR TWICE-A-YEAR FALL DISCHARGE

| Lagoon Configuration | Effluent Quality (mg/L) | | | | | | Total Number of Samples |
|---|---|---|---|---|---|---|---|
| | BOD | NFR | COD | N-TK | P-T | $NH_3$-N | |
| 1L or more | 22 | 39 | 135 | 11.9 | 4.4 | 6.9 | 25 |
| 2S 1L | 29 | 70 | 150 | 13.0 | 5.6 | 7.1 | 16 |
| 2S 2L or more | 19 | 39 | 105 | 13.3 | 4.1 | 6.9 | 24 |
| 4S 1L | 34 | 34 | 117 | 11.8 | 3.9 | 7.8 | 6 |
| 4S 2L or more | 9 | 23 | 78 | 7.3 | 3.3 | 4.3 | 80 |

TABLE D-7 LAGOON CONFIGURATION VS EFFLUENT QUALITY FOR TWICE-A-YEAR SPRING DISCHARGE

| Lagoon Configuration | Effluent Quality (mg/L) | | | | | | Total Number of Samples |
|---|---|---|---|---|---|---|---|
| | BOD | NFR | COD | N-TK | P-T | $NH_3$-N | |
| 1L or more | 54 | 41 | 162 | 21.9 | 5.2 | 18.4 | 16 |
| 2S 1L | 56 | 28 | 163 | 20.8 | 5.4 | 17.7 | 12 |
| 2S 2L or more | 78 | 43 | 182 | 24.4 | 6.0 | 19.5 | 25 |
| 4S 1L | 63 | 36 | 151 | 22.6 | 5.3 | 18.0 | 5 |
| 4S 2L or more | 52 | 27 | 147 | 25.3 | 7.2 | 20.2 | 58 |

Note: "S" - indicates anaerobic cells with short detention (2 to 5 days)
"L" - indicates facultative cell with long detention (365 days)

TABLE D-8 ACCEPTABLE WASTEWATER STABILIZATION POND CONFIGURATIONS

| Design Average Daily Flow in/$m^3$ | Anaerobic Ponds | Aerobic Treatment | Storage Pond |
|---|---|---|---|
| Less than 270 | 0 | Minimum of 60 days retention at a maximum operating depth of 1.5 m | Minimum of 1 year holding capacity at maximum storage depth of 2.5 m |
| 270 - 400 | Two in series; 3.0 to 3.6 m operating depth, with a retention of 2 - 5 days | Yes | Maximum depth: 2.5 m |
| Greater than 400 | Four in series; 3.0 to 3.6 m operating depth, with a retention of 2 - 5 days | Yes | Maximum depth: 2.5 m |

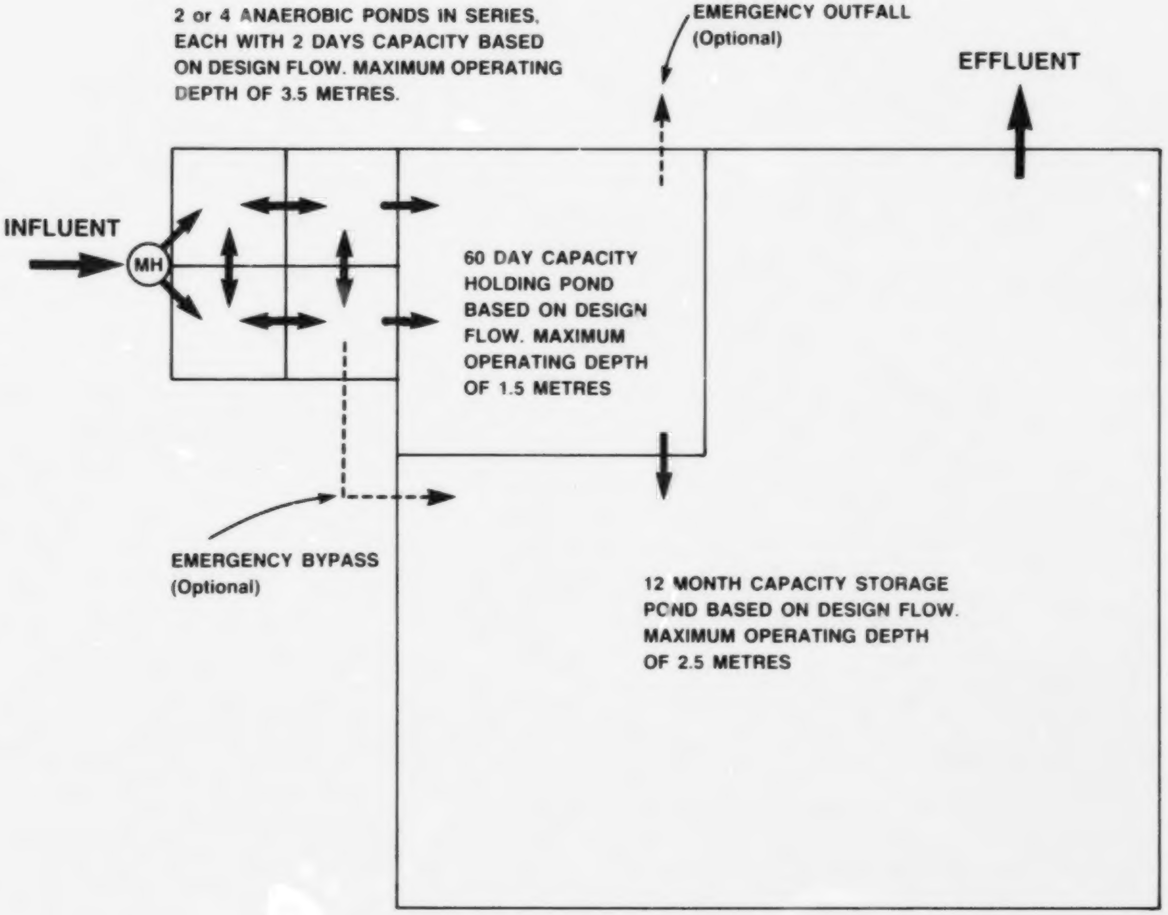
2 or 4 ANAEROBIC PONDS IN SERIES, EACH WITH 2 DAYS CAPACITY BASED ON DESIGN FLOW. MAXIMUM OPERATING DEPTH OF 3.5 METRES.
EMERGENCY OUTFALL (Optional)
EFFLUENT
INFLUENT
MH
60 DAY CAPACITY HOLDING POND BASED ON DESIGN FLOW. MAXIMUM OPERATING DEPTH OF 1.5 METRES
EMERGENCY BYPASS (Optional)
12 MONTH CAPACITY STORAGE POND BASED ON DESIGN FLOW. MAXIMUM OPERATING DEPTH OF 2.5 METRES

FIGURE D-1 A TYPICAL WASTEWATER STABILIZATION POND

## APPENDIX D-3

## SUMMARY OF THE DESIGN MODELS FOR SEWAGE LAGOONS

Prepared by Dr. D. Thirumurthi,
Professor of Civil Engineering
Technical University of Nova Scotia
Halifax, N.S.

### 1. Completely Mixed Model

Marais and Shaw suggested that a lagoon may be designed either as a completely mixed reactor or as reactors-in-series.

However, a pond cannot be rationally considered to be completely mixed because the flow regime is dispersed plug flow. Therefore the following equation has limited application.

Design Formula/Procedure

$$\frac{C_n}{C_o} = \frac{(1)^n}{(1 + kt_n)}$$

where, $C_o$ = influent BOD (mg/L)
$C_n$ = effluent BOD (mg/L) of the nth pond in series
$k$ = first-order reaction rate at minimum operating liquid temperature
$n$ = number of ponds in series
$k$ = $k_{35}\,(1.085)^{T-35}$ where, $k_{35}$ = reaction rate at 35°C = 1.20/d
$T$ = minimum operating liquid temperature (°C)

Reference

Marais (1966) and Marais and Shaw (1961)

### 2. Dissanayake Equation

Application of these formulae for cold climates should be verified by monitoring the existing field lagoons.

Design Formula/Procedure

$$\mathrm{Exp}(K_b) = 0.7716\,(1.0281)^T\,(1.0016)^C\,(0.999)^L$$

$$K_b = K_{20}\,(1.19)^{T-20}$$

$$N_e = \frac{N_i}{1 + K_b t}$$

where, $C$ = mean concentrations of algae in the pond (mg/L)
$K_b$ = first-order rate constant for removal of fecal coliforms (1/d.) at pond temperature
$K_{20}$ = first-order rate constant for removal of fecal coliforms (1/d.) at 20°C

$L$ = organic loading on the pond (kg of COD/ha·day)
$N_e$ = fecal coliform density in the pond effluent (number/100 mL)
$N_i$ = fecal coliform density in the pond influent (number/100 mL)
$t$ = mean hydraulic retention time in the pond (days)
$T$ = pond temperature (degrees Celsius)

### Reference

Dissanayake (1980) Marais (1974)

## 3. Gloyna Method

This is a semi-empirical method based on laboratory-model studies. Liquid depth = 1 m for ideal conditions (tropical to subtropical conditions; low settleable solids). Liquid depth = 1.5 m for locations with significant seasonal variations in temperature. Liquid depth = 1.5 to 2 m for severe (cold) climates.

### Design/Formula Procedure

$A = 0.35\,Q\,L_o\,(\theta)^{35-T}\,f^i\,f$ (1) (for liquid depth of 1 m)

$\frac{V}{Q} = t = 0.035\,L_a\,(\theta)^{35-T}\,f^i\,f$ (2) (for liquid depth varying from 1 to 2 m; see remarks)

where,
$A$ = pond surface area ($m^2$)
$f$ = algal toxicity factor (usually 1.0 for municipal wastewater)
$f^i$ = sulphide demand factor (1.0 when sulphate conc.<500 mg/L
$L_a$ = ultimate influent BOD or influent COD (mg/L)
$L_o$ = ultimate influent BOD (mg/L)
$Q$ = influent flow rate ($m^3$/day)
$T$ = pond liquid temperature (mean monthly temperature in °C during the coldest month)
$t$ = hydraulic retention time (days)
$\theta$ = temperature correction coefficient = 1.085
$V$ = pond (liquid) volume ($m^3$)

### Reference

Gloyna (1976)

## 4. Indian Method

This is an empirical procedure based 1970 on experience of pond operation in India. (This formula or its modified form may have a potential application in Canadian North.)

### Design/Formula Procedure

$L_{des} = 375 - 6.25\,L$

where,
$L_{des}$ = design organic loading (kg of BOD/ha·day)
$L$ = latitude (range in India = 8 to 36°N)

### 5. McGarry and Pescod Method

An empirical relationship based on 134 primary facultative ponds was supposed by the author.

Design Formula/Procedure

$$L_r = 9.23 + 0.758 \, L_a \quad (1)$$

where, $L_a$ = applied BOD loading (kg/ha•d)

$L_r$ = BOD removed (kg/ha•d) (based on unfiltered influent sewage and filtered effluents of 134 ponds throughout the world)

Reference

McGarry and Pescod (1970); McGarry (1982)

### 6. McGarry and Pescod Method

An empirical model derived from data on 143 existing ponds.

Design Formula/Procedure

$$L_{max} = 11.2\,(1.054)^T$$
$$L_{des} = 7.5\,(1.054)^T$$

where, $L_{max}$ = maximum BOD (surface) loading (kg/ha•d) that could be applied to a pond before it failed (i.e. became completely anaerobic)

$L_{des}$ = design load or permissible BOD loading (kg/ha•d)

$T$ = mean monthly ambient air temperature (°C)

Reference

Mara (1976)

### 7. Non-Linear Multiple Regression Method

BOD removal coefficient was considered to be a function of mean residence time, volumetric BOD loading and mean liquid temperature. It was estimated by regression analysis of data from laboratory model studies. This method has good potential for application, with or without modification, for cold climates.

Design Formula/Procedure

$$K = t^{o}(-1/(1.391 + 1.304/T) + (0.061 + 0.5T/L)/(0.327 + 10.277/T + 1/(L(0.25 + 0.476/T)))$$

where, $K$ = first order BOD removal coefficient ($^1/d$)

$L$ = volumetric organic (BOD) loading (g/m$^3$•d)

$t$ = mean residence time (days)

$T$ = mean liquid temperature (°C)

The value of K (derived from lab. models) covers a broad range of t (4 to 100 days), L (1 to 25 g/$m^3$•d), and T (2° to 40°C).

Reference

Uhlmann, et al., 1983, and Uhlmann (1979)

## 8. Plug Flow Model

This model is simple to use but independent of available solar energy.

Design Formula/Procedure

$$\frac{C_e}{C_i} = e^{-kt}, \text{ where } k = k_{20}(1.09)^{T-20}$$

where,
$C_e$ = effluent BOD (mg/L)
$C_i$ = influent BOD (mg/L)
$k$ = plug flow reaction rate ($day^{-1}$) at pond temperature
$k_{20}$ = plug flow reaction rate ($day^{-1}$) at a standard temperature of 20°C
$t$ = hydraulic retention time (days)
$T$ = minimum operating pond temperature

The value of k varies with BOD loading rate as shown below:

| BOD Loading Rate (kg/ha•d) | Value of k ($day^{-1}$) at 20°C |
|---|---|
| 22 | 0.045 |
| 45 | 0.071 |
| 67 | 0.083 |
| 90 | 0.096 |
| 112 | 0.129 |

Reference

Neel, et al., 1961, and Middlebrooks et al., 1982

## 9. Thirumurthi Method (Approximate Plug Flow Model)

Derived by analysis of data from laboratory-model as well as field lagoons in Missouri, Israel, Wisconsin, and Ontario. For most practical applications, a plug flow formula is adequate. The relationship between K and $K_s$ should be re-examined and modified with the aid of data published in the recent literature and by means of more studies of physical models.

$$\frac{C_e}{C_l} = e^{-Kt}$$

where, $K = K_s \cdot C_{Te} \cdot C_{Tox} \cdot C_o$
$C_{Tox}$ = usually 1.0 for municipal wastes

$C_{Te}$ = $(1.036)^{T-20}$

$C_o$ = $1 - \frac{0.083}{K_s} \log_{10} \frac{(60)}{(L)}$

$C_e$ = effluent BOD (mg/L)

$C_i$ = influent BOD (mg/L)

$C_o$ = correction factor for organic load

$C_{Te}$ = correction factor for liquid temperature

$C_{Tox}$ = correction factor for toxic industrial wastes

$K$ = first-order BOD removal coefficient (1/d) at lagoon environmental conditions

$K_s$ = first-order BOD removal coefficient (1/d) at standard environmental conditions

$L$ = surface area organic load (lb of BOD/acre•day)

$t$ = mean detention time (days)

$T$ = mean temperature of pond contents during the coldest winter months (°C)

Reference

Thirumurthi (1969, 1974)

## 10. **Thirumurthi Method Using Wehner & Wilhelm Equation (Dispersed Plug Flow Model)**

$$\frac{C_e}{C_i} = \frac{4a\, e^{1/2d}}{(1 + a)^2 e^{a/2d} - (1 - a)^2 e^{-a/2d}}$$

where, $a$ = $(1 + 4Ktd)^{0.5}$

$d$ = dispersion number (suggested values range from 0 to 0.5)

(All other notations have been defined in the preceding section on Plug FLow Model, Thirumurthi Method)

# APPENDIX D-4

## SEWAGE LAGOON DESIGN CRITERIA

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Edited version of "Design Criteria for Waste Stabilization Ponds" by Dr. D. Thirumurthi Dept. of Civil Engineering, Technical University of Nova Scotia first published in 1974 in the Journal of the Water Pollution Control Federation Vol. 46 (9) pp. 2094-2106.

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Dr. Thirumurthi has defined lagoons as biological reactors governed by first-order biochemical oxygen demand removal kinetics and recommended a series of equations as a basis for their rational design. He has integrated the theoretical concepts with data from laboratory and field studies in determining the design parameters.

The principal design parameter is the first-order BOD removal coefficient, K. Several environmental factors and field conditions influence pond performance and therefore the magnitude of K. Temperature, organic load, visible solar energy, toxic industrial wastes, pond shape and mixing characteristics and benthal load are factors considered.

A set of standard environmental conditions are assumed to determine a standard value $K_s$ of the first order BOD removal coefficient. The standard environment consists of:

> (a) pond temperature of 20°C, (b) and organic load of 60 lb/day·acre (67.2 kg/ha·day), (c) absence of industrial toxic chemicals, (d) minimum visible solar energy at the rate of 100 langleys/day, and (e) absence of benthal load.

The design BOD removal coefficient K corresponds to the actual environment of the lagoon. It is up to design engineer to select a suitable equation from the following three formulas.

**Accurate dispersed plug flow formula**

$$\frac{Ce}{Ci} = \frac{4ae^{1/2d}}{(1+a)^2e^{a/2d} - (1-a)^2e^{-a/2d}} \qquad (1)$$

Modified formula:

$$\frac{Ce}{Ci} = \frac{4ae^{1-a/2d}}{(1+a)^2} \qquad (2)$$

Approximate Plug Flow Formula:

$$\frac{Ce}{Ci} = e^{-Kt} \qquad (3)$$

where, Ce = effluent biochemical oxygen demand (BOD) (mg/L),
Ci = influent BOD (mg/L),

K = first order BOD removal coefficient ($day^{-1}$), at lagoon liquid temperature
t = mean detention time (days),
a = $(1 + 4\,Ktd)^{1/2}$
d = $\frac{D}{UL} = \frac{Dt}{L^2}$
d = dimensionless dispersion number,
D = axial dispersion coefficient (sq·ft·/hr), ($m^2/h$)
U = fluid velocity (ft/hr) and (m/h)
L = length of fluid travel path from influent to effluent (ft.), (m).

Equation 1, originally derived by Wehner and Wilhelm (1956) for chemical reactors governed by first-order chemical reactions, has been proven applicable to biological waste treatment systems.

The dispersion number (diffusivity constant) defines the hydraulic flow pattern within the system. A value of zero indicates plug flow and a value of infinity indicates completely mixed flow. Values in between the two extremes show that the system is incompletely mixed.

A design chart was developed by Thirumurthi in 1969 to facilitate the use of the Wehner and Wilhem equation. It may be used to design waste treatment systems government by ideal plug flow (trickling filters), completely mixed flow (aerated aerobic lagoons), and intermediate flow patterns (conventional facultative lagoons and aerated facultative lagoons). The key to the design is the evaluation of K and d. The latter can be estimated from tracer studies in laboratory-model tanks or in field lagoons.

When actual environmental conditions deviate from one or more of the five defined standard conditions, suitable correction factors must be incorporated.

$$K = K_s C_{Te} C_o C_{Tox} C_{vse} \qquad (4)$$

where,
K = first order BOD removal coefficient (1/d) at lagoon environmental conditions
$K_s$ = first order BOD removal coefficient (1/d) at standard environmental conditions
C = correction factor,
Te = correction for temperature,
o = correction for organic load
Tox = correction for industrial toxic chemicals
vse = correction for visible solar energy.

**Temperature $C_{Te}$ correction factor.**

The suggested correction[5] is

$$C_{Te} = \theta^{T-2D} \qquad (5)$$

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[5] Suwannakarn, V., "Temperature Effects on Waste Stabilization Pond Treatment." Ph.D. thesis, Univ. of Texas, Austin (1963).

$T$ = average temperature of lagoon contents in the critical or coldest winter month (°C)
$\theta$ = temperature coefficient

The temperature coefficient is not a constant and must be determined for the average temperature T. $\theta$ may be determined in the laboratory by placing laboratory-scale lagoons under identical conditions except for maintaining them at different temperatures. From the resulting data, the BOD removal coefficient K is calculated for maintaining each lagoon and plotted as a function of temperature on semilog paper. A straight line of best fit is drawn by the method of least squares to define the equation.

$$K = K_{20} (\theta)^{T-20} \tag{6}$$

The temperature coefficient $\theta$ is determined from the slope of the line. For the standard temperature of 20°. $\theta$ varies from 1.030 to 1.055. Dr. Thirumurthi uses 1.036 for design purposes.

A second trial and error method is to assume values of $\theta$ say from 1.01 to 1.085. For the various assumed values of $\theta$ the corresponding K values are determined for the different temperatures of the laboratory scale lagoons and compared with the actual K values from the laboratory studies. The standard deviations of the differences between the theoretical and actual values are plotted as a function of $\theta$. The least value for the standard deviation from the resulting curve corresponds to the actual $\theta$ value.

The results of these methods are illustrated in Figures D-2 and D-3 based on data published by Survannakarn in Texas using $T = 35°C$ as the standard lagoon temperature.

**Organic load ($C_o$) correction factor.** The BOD removal coefficient K generally decreases when the organic load is decreased. In other words, for a constant influent BOD, the efficiency of a pond does not increase significantly when the organic load is decreased. A lessening of the rate of increase in efficiency often occurs when detention time is increased or organic load is decreased unnecessarily.

A design equation was suggested by Thirumurthi[1] to develop a correlation between organic load L and BOD removal coefficient K based on the results published by Neel et al.[10] at Fayette, Mo and nonideal flow conditions.

$$Co = 1 - \frac{0.083}{K_s} \log_{10} \frac{60}{L_1} \tag{7}$$

where, $L_1$ = organic load in lb/acre/day (proposed or intended value), and
$60$ = standard organic load in lb/acre·day (67.2 kg/ha·d).

corresponding to the standard value, $K_s$.

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[1] Thirumurthi, D., "Design Principles of Waste Stabilization Ponds". Jour. San. Eng. Div., Proc. Amer. Soc. Civil Engr., 95, SA2, 311 (1969).

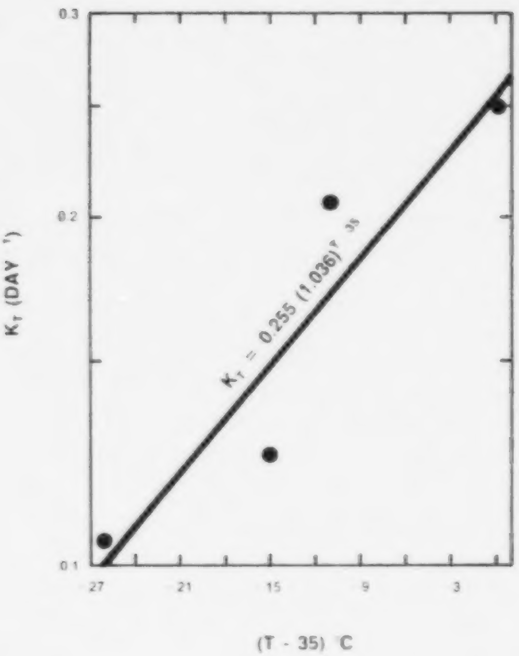

FIGURE D-2. -- First order biochemical oxygen demand removal coefficient, $K_t$, as a function of temperature.

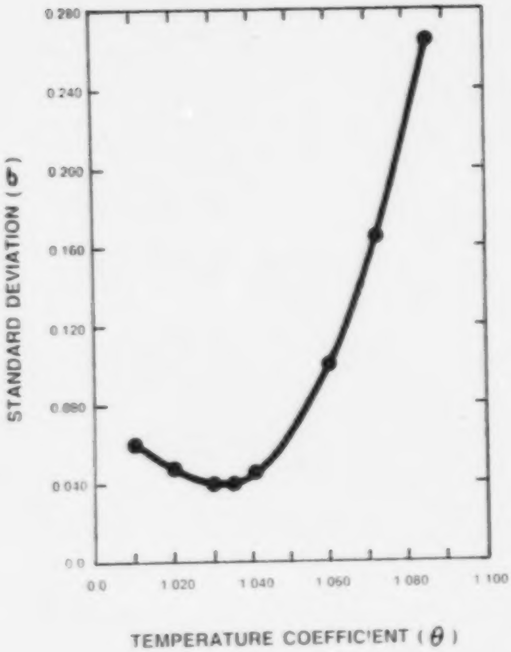

FIGURE D-3. -- Standard deviation for various assumed values of R.

This value of $K_s$ has been successfully shown to be universally applicable to field ponds in Ontario, Herzliya, Israel; Fayette, Mo.; and in three different cities in Wisconsin.

**Toxicity, $C_{Tox}$ correction factor.** In the absence of industrial wastes, the factor $C_{Tox}$ will equal unity. Laboratory investigations at the University of Texas[13,14] indicated that, in the presence of certain industrial organic compounds, green algae could not synthesize chlorophyll pigment. Without chlorophyll production, photosynthesis cannot be prolonged by algae and, therefore, oxygen production wll stop. The resultant decrease in dissolved oxygen (DO) concentration in the pond will result in a drastic reduction in BOD removal efficiency. Ponds designed to treat toxic industrial wastes will perform at lower efficiencies and, thus, $C_{Tox}$ values must be determined by laboratory investigations or by previous field experience.

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[13] Thirumurthi, D., "Relative Toxicity of Organics to Chlorella pyrenoidosa." Ph.D. thesis, Univ. of Texas, Austin (1966).

[14] Gloyna, E.F., and Thirumurthi, D., "Suppression of Photosynthesis Oxygenation." Water & Sew. Works, 114, 3, 83 (1967).

**Visible solar energy.** In most parts of the world sunlight is not a limiting factor for supporting photosynthesis. Work at the Technical University of Nova Scotia[15] has demonstrated that sunlight is a limiting factor from the standpoint of dissolved oxygen concentration in the lagoon effluent especially whenever ice cover exists in the winter months at northern latitudes. The presence of ice with an overlaying layer of snow drastically limits the incident light-energy that reaches the liquid in a sewage lagoon. According to Mackenthum and McNabb[4], 1.5 in (3.8 cm) thickness of snow over 15 in (38 cm) thickness of ice on a lagoon surface resulted in 90 percent reduction in the incident light energy.

Neel et al.[10] conducted a very extensive scientific field study on five identical ponds and a sixth larger pond. Information about BOD removal efficiencies and DO concentrations in these lagoons ponds were plotted as a function of available visible energy showing conclusively that DO concentration drops in winter months when visible solar energy drops; whereas the BOD removal efficiency does not drop correspondingly.

There is a critical energy level, A, below which a drop in photosynthetic oxygenation (or DO concentration in the effluent) of the stabilization pond may be expected.

The A level, based on desirable dissolved oxygen concentration in the pond, may be established by using the values suggested by Neel et al.,[10] who reported that "If ice cover need not be considered, it would appear that a minimum monthly solar radiation level averaging around 150 to 160 langleys/day (based on total spectrum) would furnish enough light to maintain oxygen in ponds loaded up to 100 lb BOD/day•ac (1 120 kg/day•ha). This relationship suggests that a minimum of 1.5 langleys per day are needed for each pound of BOD applied per acre."

The standard environmental conditions include a standard organic load of 60 lb/day•acre (67.2 kg/day•ha). Correspondingly, the minimum required total solar energy level is 90 langleys/day, or approximately 25 langleys of visible solar energy a day. The critical value of A of 25 langleys/day, corresponding to the standard organic load of 60 lb/acre•day (67.2 kg/day•ha). Expressed in terms of the units suggested by Neel et al.[10] This means that approximately 0.4 langleys (visible) are required to meet the demands of each pound of BOD applied per acre.

There is another critical energy level B, below which a reduction in the BOD removal efficiency in the sewage lagoon may be expected. Parallel laboratory studies at TUNS (15) using model lagoons of different depths and varing visible radiation energy clearly demonstrated that dissolved oxygen concentrations sampled at noon) decreased

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4. Mackenthum, K.M., and McNabb, B.D., "Stabilization Pond Studies in Wisconsin." Jour. Water Poll. Control Fed., 22, 1234 (1961).

10. Neel, J.K., et al., "Experimental Lagooning of Raw Sewage, Fayette, Missouri, Experimental Stabilization Ponds, 1957-58." Jour. Water Poll. Control Fed., 33, 603 (1961).

15. Klaamas, P., "Design of Waste Stabilization Ponds." Undergraduate thesis, Nova Scotia Technical College, Halifax, Can. (1968).

significantly as the incident light energy decreased. The results also showed that for the deeper ponds the BOD removal efficiency also decreased where there was insufficient visible energy to support the required photosynthesis.

From these studies a critical energy level B was proposed subject to verification by field studies. For shallow ponds (less than 3 ft (91.5 cm) deep an energy level of about 0.1 langleys (visible spectrum)/lb of organic load/acre (0.54 langleys/kg•ha) may be sufficient. However, for deeper ponds (deeper than about 3 ft (91.5 cm)) 0.2 or more langleys/lb of organic load/acre (1.09 langleys/kg•ha) may be needed. In other words, the standard environment must have 6 to 12 langleys/50 lb or organic load/acre (0.65 to 1.3 langleys/kg•ha) to satisfy the critical level B requirements.

Without field data, a safety factor should be applied to the laboratory results as the environmental factors are more favourable and better controlled than in the real world.

**Evaluation of $K_s$.** Data from three published papers (4,9,10) and the stabilization pond at New Hamburg, Ontario (19) were used as a basis for evaluating $K_s$ assuming:

1. Plug-flow existed in all the selected field ponds because tracer studies were not conducted by the authors.
2. Toxic industrial wastes inhibitory to algal growth were absent or insignificant in all the ponds studied.
3. The influences of pond depth and benthal load were not considered in this study because a critical review of their effects and correction factors to determine their relationship with pond performance were not available.

The average values of $K_s$ (day$^{-1}$) at 20°C and 60 lb/acre•day organic load were calculated from the field data knowing the average lagoon temperatures, ratio of influent BOD to effluent BOD, organic surface loading, waste flow, the detention time and visible solar energy level. (The conversion factors used were: 1 lb/acre•day x 0.112 = g/d•m$^2$; imp. gal/day x 0.004545 = m$^3$/day; gpd/acre x 0.00935 = m$^3$/day•ha; lb/day•acre x 0.112 = g/d•m$^2$; in x 2.54 = cm.)

The average value of $K_s$ for all the ponds included in this study was 0.056/day and the range was 0.042 to 0.071/day. The field coefficient K varied from a low of 0.0017/day to a high of 0.128/day (Herzliya, Israel, 27°C) (New Hamburg, Ontario - June at 21°C).

The fluctuations in $K_s$ would have been even less if the average influent and effluent BOD$_5$ had been used for each lagoon. Individual values of $K_s$ are not as meaningful because values of the waste characteristics in all ponds fluctuated greatly from day to day. The effluent BOD on a given day was really a result of the influent waste on a day approximately one detention time before.

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9. Meron, A., et al., "Quality Changes as a Function of Detention Time in Wastewater Stabilization Ponds." Jour. Water Poll. Control Fed., 39, 12, 1657 (1967).

19. Annual Report, Town of New Hamburg, Ontario, Can. (1966).

Dr. Thirumurthi stressed that:

1. A sewage lagoon must be designed to suit local environmental conditions.
2. The first-order BOD removal coefficient K being the key to the design should be determined individually for each pond.
3. The selected standard coefficient, $K_s$, is a constant for domestic wastes. K is estimated by correcting the value of $K_s$ for temperature, organic load, toxic industrial wastes, and incident solar energy.
4. Two critical solar (visible) energy levels, A and B, have been proposed. When the available radiant energy is less than the level A, the dissolved oxygen concentration in the pond effluent will be significantly reduced. When the intensity is below level B, a drastic reduction in BOD removal efficiency is expected.

## APPENDIX D-5

# OPERATOR TRAINING CONCEPT

by Yves Dubuc P. Eng.
Kativik Regional Government

**Basic requirements.** In Québec, the basic courses to become a wastewater treatment plant operator are either a specialized 3 year technical course at the college level or a certificate from certain schools that give the required 1200 hours of water and wastewater treatment courses.

In most permafrost areas, native people will be the operators of the ponds. It would be difficult to meet the above-mentioned requirements for most of them. For these reasons it is logical to modify the course so it is adapted to the northern workforce instead of importing a non-native operator on a permanent basis.

**Group training.** In Northern Québec, the municipalities are aware of each other and, whenever possible, the different organisms that work in the territory try to develop a sense of community solidarity. The Kativik school board (KSB) for example, has an adult education facility in a centrally located municipality and brings people from the 13 other municipalities to follow specialized technical courses. This seems to bring people from different municipalities and backgrounds together and allows friendships to develop. This will benefit most trainees later on when they need to consult someone readily available on a problem he or she has encountered on the job.

In a global view of northern operator training, creating a brotherhood of operators in a certain region will only reinforce the motivation and care the operators bring to their job.

For some, these human considerations may look like a waste of time. My experience in training and working with Inuit and non-Inuit as well, tells me that you may have the best candidate in the world but that this talent will be wasted if he or she feels isolated in this work. This is especially true with wastewater treatment plant operators for obvious reasons.

**The language.** The course should be given in the trainees' mother tongue. The teachers would then be using a translator in the classroom. It is clear that the translator will be given the course first so that he or she is able to prepare and find the right words for technical or unusual terms. This will also be an opportunity for the teacher to evaluate his or her course.

**The classroom material.** Notes, manuals, exams etc., will be in native language and abundantly illustrated. Visual learning is always indicated in a training course.

**The place.** Considering past experiences, it is preferable to have the course in the trainees' general area. It is always difficult for most people to be away from home and family for an extended period of time; if on top of that the trainee is submitted to distractions from a foreign environment, he or she will rapidly loose interest and ask to go back home.

If chosen place is also equipped with a wastewater treatment system so much the better. This is the case in Northern Québec with the municipality of Salluit.

Note: What follows is based on Environment Québec's "Directive no. 006 - Formation des opérateurs - Opération des équipements d'aqueduc et d'égout".

**The course.** The course for the operator has to be related to the process, the works and equipments he or she has to operate. The trainee must then, after he or she completed the prerequisites, follow a specific path that will include all the necessary courses for his or her type of system. On the next page are all courses related to oxidation ponds and possible paths.

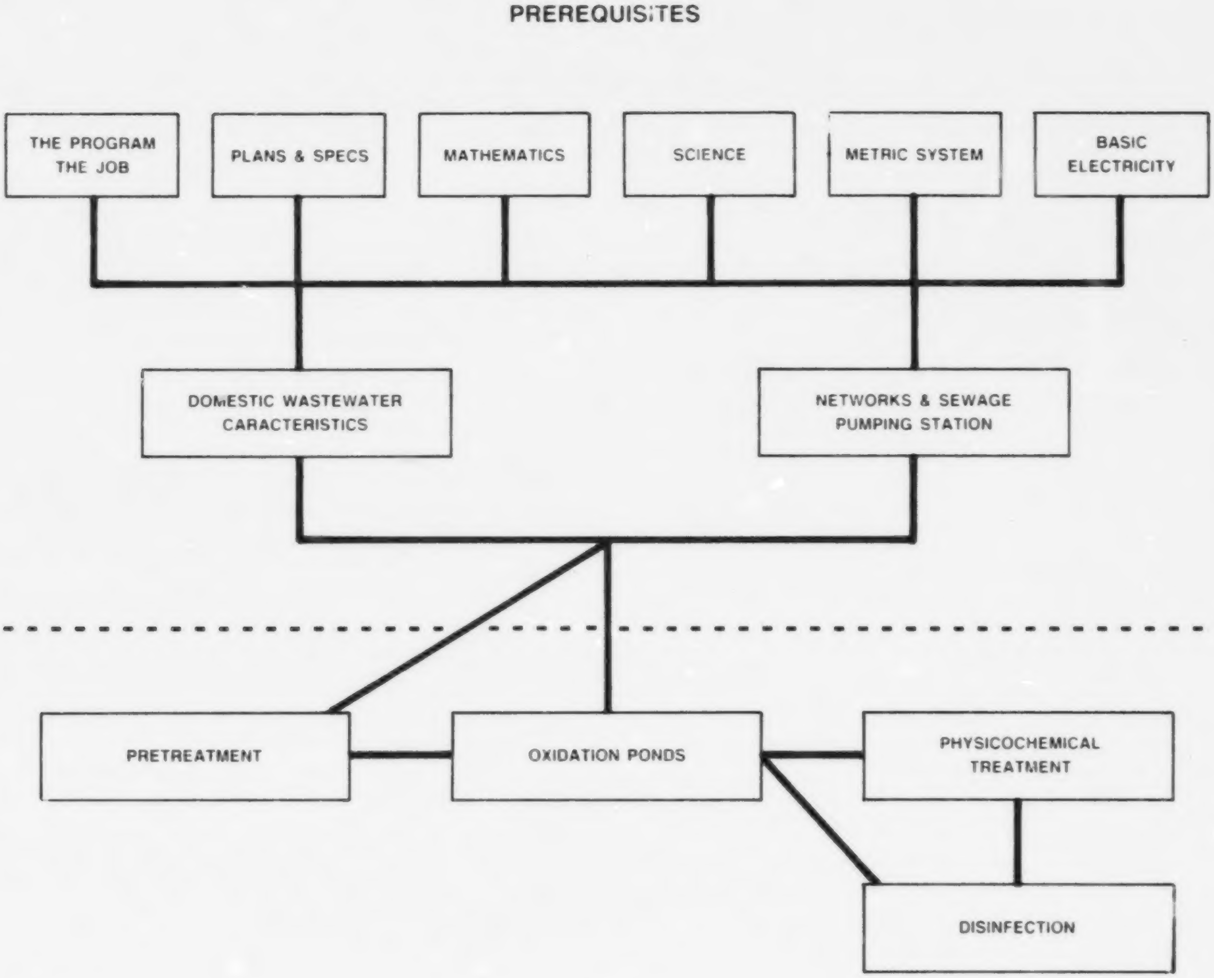

FIGURE D-4 SUBJECTS OF STUDY AND THEIR APPLICATION

The total number of hours for each course is given below:

| | |
|---|---|
| The program, the job | 15 |
| Plans & specs | 15 |
| Mathematics | 30 |
| Science | 45 |
| Metric system | 15 |
| Basic electricity | 15 |
| Domestic wastewater characteristics | 60 |
| Networks & wastewater pumping stations | 30 |
| **Subtotal (prerequisites)** | 225 |
| Pretreatment | 15 |
| Oxidation ponds | 15 |
| Physicochemical treatment | 45 |
| Disinfection (chlorination and ozonation) | 60 |
| **Subtotal (for the four courses)** | 135 |
| **Total** | 360 |

This is what is recommended by Environment Québec. The WPCF wastewater treatment skill training package could fit in the oxidation pond course of 15 hours. The total number of hours for all courses may seem a lot but I insist that having a well trained operator is a must. The prerequisite courses are, in my view, the most important part of the training. They will provide basic knowledge that will help the operator really understand what he is dealing with and what are the processes involved in the treatment. However some courses will have to be adapted to the trainee's capacity and type of system.

The training period could be broken down in 1 three week period and 3 two week periods. In Northern Québec more oxidation ponds will be constructed in the summer of 1986. The training session will be done during the construction so that the trainees will be able to work on the construction site during the breaks between the periods. This approach has many advantages such as practical knowledge of the pond the trainee will operate, an opportunity to apply knowledge from the course on the actual site and a sense of continuity between the construction and operation of the pond.

**The participants.** In most northern communities and municipalities, water and wastewater services are done by trucks. I suggested that the operation be done by the drivers: they are already municipal employees, they are used to dealing with wastewater and, in Northern Québec, they are the group that has had the lowest turnover rate.

**The teacher.** The best teacher would be an operator with several years of experience. He or she would be able to create an atmosphere of commitment and be able to share with the trainees operational problems he or she previously encountered.

**Conclusion.** This is a preliminary outline of what should be a training program for wastewater system operators. I find it necessary that the content of training programs in Canada or at least in a given province or territory be standardized and not be left to local authorities. This way, the ultimate goal of achieving operating efficiency and good quality effluents across the country could be reached.

# APPENDIX E

# DISPLAYED DOCUMENTS ABOUT COLD-CLIMATE LAGOONS

(The publications listed in this appendix are in addition to those listed in "Sewage Lagoons in Cold Climates", Environment Canada, Report EPS 4/NR/1, March 1985.)

## E.1 Provincial Governments

### New Brunswick

1. Environment New Brunswick, Pollution Control Branch, "Summary of Operating Conditions of Wastewater Treatment Plants Province of New Brunswick", No. T-8403, 1984 and No. T-8304, 1983.

### Québec

1. Jalbert, J.-M., "Les Étangs Facultatifs Aérés Théorie et Pratique," Minitère de l'Environnement, Service de l'assainissement urbain.
2. Jalbert, J.-M., "Étude Sur l'Efficacité des Étangs Aérés Facultatifs de la Ville du Lac-Etchemin", Ministère de l'Environnement, présentée dans le cadre de la 22e conférence régionale annuelle de l'Association québécoise des techniques de l'eau - Chapitre de l'Estrie.

### Ontario

1. Limnos Ltd., "Environmental Significance of Sewage Lagoons in Ontario", Provincial Lottery Project No. 164, March 1982.
2. Limnos Ltd., "Summary Report on Walleye Culture - Port Perry Lagoon 1984", Report to Ministry of Natural Resources, January 1985.
3. Townshend, A.R., Ontario Water Resources Commission, Toronto, "Statistical Analysis of the Effluent Quality of Biological Sewage Treatment Processes", Proceedings, The Third Canadian System on Water Pollution Research, University of Toronto, Vol. 3, Feb. 1968, pp. 272-293.
4. Townshend, A.R., Ontario Water Resources Commission, "Status Report on The Design, Cost and Performance of Aerated Lagoons in Ontario", Paper Presented at the 35th Annual Conference. The Canadian Institute on Pollution Control, Hamilton, Ontario, October 20-23, 1968.
5. Research Publications from the Ontario Ministry of the Environment (MOE):
    - Andrews, R.H.G., "Gravity Filtration of Algal Suspensions";
    - Black, S.A., "Review of Effluent Polishing Pilot Plant Study Brampton - Chinguacousy WPCP";
    - Black, S.A., "Supplementary Aeration of Waste Stabilization Ponds for the Treatment of Industrial Wastes";
    - Christie, A.E., "Virus Reduction in the Waste Stabilization Pond";
    - Ehlert, N.G., "Land Disposal of Lagoon Effluent at Shelburne";
    - Ehlert, N.G., "The Effects of Alum Injection on the Effluent from Continuous Discharge Lagoons";

    - Fielding, M.B., "Waste Stabilization Pond Berm Erosion";
    - Lewandowski, W. and B. Bradley, "A Survey of Aerated Lagoon Performance";
    - Shikaza, K., "Aerated Lagoons for the Treatment of Cannery Wastes".

6. Research Reports; Canada/Ontario Agreement on Great Lakes Water Quality:
    - Boyko, B. and J.W.G. Rupke (MOE), "Phosphorus Removal Within Existing Wastewater Treatment Facilities;
    - Ehlert, N.G. (MOE), "Spray Runoff Disposal of Waste Stabilization Pond Effluent";
    - Graham, H.J. and R.B. Hunsinger (MOE), "Phosphorus Reduction from Continuous Overflow Lagoons by Addition of Coagulants to Influent Sewage";
    - Graham, H.J. and R.B. Hunsinger (MOE); "Phosphorus Removal in Seasonal Retention Lagoons by Batch Chemical Precipitation";
    - Pollutech Pollution Advisory Services Ltd., "Nutrient Control in Sewage Lagoons" vol. I and II.

### Manitoba

1. Environmental Management Division, Environmental Control Services, "Recommended Operation and Maintenance of Sewage Lagoons", No. ES 216, October 1983.

2. Environmental Management, Province of Manitoba, "Design Objectives for Standard Sewage Lagoons", No. ES 145, March 1985.

3. Metropolitan Corporation of Greater Winnipeg, Waterworks and Waste Disposal Division, "Evaluation of Aerated Lagoons in Metropolitan Winnipeg", March 1970.

### Saskatchewan

Publications numbered 1 through 12 are published by Saskatchewan Environment, Water Pollution Control Branch.

1. "A Guide to Aquatic Nuisances and Their Control".

2. "Lagoon Problems - Investigative Protocol".

3. "Multi-Cell Sewage Lagoon Performance, City of Lloydminster 1971-1976", No. WPC-16, March 1977.

4. "Municipal Facility Classification and Voluntary Operator Certification Program", second edition, June 1981.

5. "Municipal Sludge Disposal to Land".

6. "Overview of Lagoon Problems in Saskatchewan", June 1985.

7. "Remote Sensing Utilizing Colour Infrared Film for Lagoon Seepage Detection", March 1985.

8. "Saskatchewan Regulation 3/80, The Water Resources Management Act - Section 41". January 1980.

9. "Sewage Effluent Irrigation Guidelines", June 1976, revised October 1983.

10. "Two-Cell Lagoon Operation and Maintenance," March 1983.

11. "Water Quality Objectives," January 1975, reprinted September 1983.

12. "Waterworks and Sewage Works Design Guides," draft.

13. Saskatchewan Research Council," A Demonstration Project at Humboldt to Provide Tertiary Treatment to the Municipal Effluent Using Aquatic Plants," by G. Lakshman, SRC Technical Report No. 129, Publication No. E-820-11-B-82, May 1982.

### Alberta

1. Alberta Environment, Earth Sciences Division, "A Practical Guide to Municipal Wastewater Irrigation," June 1984.

2. Hogge, H.L., Alberta Dept. of Public Health, "Sewage Treatment Capabilities of Short and Long Detention Ponds", Papers Presented at the Fourteenth Annual Convention, Western Canada Water and Sewage Conference, Calgary, Alberta, Sept. 27 and 28, 1962, pp. 139-173.

3. Reid, Crowther, and Partners Ltd., et al, "Rapid Infiltration - A Design Manual 1981", for Alberta Environment and The City of Red Deer, May 1981.

Publications numbered 4 through 9 are published by Alberta Environment, Standards and Approvals Division:

4. "Cold Climate Lagoons Workshop, Winnipeg, Manitoba, June 5-7, 1985, Appendices I to IV; Alberta Clean Water Act Legislation, Standard Conditions for Permits and Licences, Engineering Reviews and Standards Revisions, Treatment Performance and Evaluation".

5. "Design and Construction of Liners for Municipal Wastewater Stabilization Ponds".

6. "Flexible Synthetic Liners and Their Use in Liquid Waste Impoundments", April 1984.

7. "Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Lands".

8. "Policy Document on Land Application of Municipal Wastewaters in Alberta", May 1979.

9. "Alberta Environment Standards for Water Supply and Sewage", 1978. This standard publication will be replaced in 1987 by a publication entitled," Standards for Water Supply Facilities, Sewage Works, and Stormwater Drainage Systems."

British Columbia

1. British Columbia Water and Wastewater Operators Certification Program, Certification Board, "B.C. Water and Wastewater Operators Voluntary Certification Program and Municipal Facility Classification", April 1979.

Yukon Territory

1. Yukon Territory Water Board, "Guidelines for Municipal Wastewater Discharges in the Yukon Territory", March 1983.

Northwest Territories

1. Christensen, V., "General Guidelines for the Planning and Preliminary Engineering of Appropriate Sewage Treatment/Disposal Systems for Small Northern Communities", Department of Local Government, Yellowknife, N.W.T., July 1982.

## E.2 Canadian Federal Government

**Environment Canada, Environmental Protection Service:**

1. Kent, R.J., Northwest Territories District Office, "Consulting the Development of Municipal Effluent Guidelines for the Northwest Territories", from IAWPRC Proceedings, Yellowknife, N.W.T., 1985.

2. Metikosh, S., V.W. Cairns and B.E. Jank, Wastewater Technology Centre, "Toxicity Assessment of Treated Municipal Effluents", report no. EPS 4-WP-80-1, February 1980.

3. Ross, S.A., M.G. Boivin and D.L. Caverson, Industrial Programs Branch, "Operation and Maintenance Costs for Municipal Wastewater Treatment Facilities in Canada - 1980", report no. EPS 5/UP/1, December 1984.

**Indian and Northern Affairs Canada**

1. Crowley, F., Municipal Services Division, "Facultative Lagoon Development Guidelines", report no. TSD-41-3, January 1985.

2. Cullimore, Dr. D.R., and Dr. A. Maule, Regina Water Research Institute, "A Study of the Microbiology of Sloughs Receiving Human Effluent to Determine the Hygienic Safety of Such Practices", RWRI report no. 30, Feb. 1982, revised Feb. 1984.

3. Engineering and Architecture Manual, Part 41, DRM/GM 10-7, "Lagoons", pp. 26-32, November 1984.

4. Soniassy, R. and R. Lemon, Water Resources Division, Northern Affairs Program, "Lagoon Treatment of Municipal Effluent in a Subarctic Region of Canada (Yellowknife, N.W.T.)". IAWPRC International Conference on Arctic Water Pollution Research, Yellowknife, N.W.T., April 28-May 1, 1985, Section V-3.

## E.3 Canadian Universities

1. Brière, F., Le Centre de Développement Technologique de l'École Polytechnique de Montréal, "Étude du Traitement des Eaux Usées par des Tourbières au Campement Fontanges, Rapport Final, 2ième année d'opération", préparé pour Société d'Énergie de la Baie-James, Montréal, Projet CDT P728, Juin 1984.

2. Henry, J.G., D. Prasad and M. Michael, Dept. of Civil Engineering, University of Toronto, "Microbial Aspects of the Inuvik Sewage Lagoon". IAWPC International Conference on Arctic Water Pollution Research. Yellowknife, N.W.T., April 28 - May 1, 1985, Section V-2.

3. Héroux, J.A., Dept. of Civil Engineering, Royal Military College of Canada, Kingston, "The Impact of Raw Wastewater Discharge to Alert Inlet", Proceedings, Cold Regions Engineering Specialty Conference, April 4-6, 1984, Canadian Society for Civil Engineering, Montreal, pp. 861-877.

4. Leblanc, D. and R. Labonté, Centre d'Ingénierie Nordique de l'École Polytechnique de Montréal, "Épuration des eaux usées domestiques par le langage naturel facultatif à microphytes sous un climat froid", CINEP No. 665-339, Décembre 1983.

5. Murray, G.E., et al, Biology Dept., University of Ottawa, "Effect of Chlorination on Antibiotic Resistance Profiles of Sewage - Related Bacteria", Applied and Environmental Microbiology, Vol. 48, No. 1, July 1984, pp. 73-77.

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# APPENDIX F
# WORKSHOP EVALUATION

(based on information taken from Evaluation Sheets)

# F WORKSHOP EVALUATION

## F.1 Comments on the Success of the Workshop

- good preparatory efforts by organizers with regard to materials mailed out;
- brought together a good mix of participants having relevant experiences/needs - regional and sector representation;
- good physical layout conducive to informal discussion;
- leadership succeeded in keeping program focussed on key issues;
- good delegate participation and information exchange;
- quality of information/ideas presented;
- met overall objective to identify priority areas for further study.

## F.2 Some Shortfalls of the Workshop

- some participants had a misconception regarding the objectives of the workshop;
- lack of preparation by participants;
- sessions could have been chaired more tightly;
- not enough time for real in-depth discussion of identified problems;
- room to small;
- some slides/overheads poor.

## F.3 Comments on the Organization of Future Workshops

- prepare and distribute problems in advance - leave more time to discuss solutions;
- participants should arrive prepared according to precise instructions;
- at the beginning, take time to explain the aims and procedure to reach results;
- select a number of small groups of experts in a certain field who deliberate and report to the whole membership on issues decided upon in advance;
- hold a preliminary forum consisting of several smaller groups with a combined forum to follow;
- use small brainstorming groups with the chairman of each reporting back to the general forum;
- allow more time to meet participants/personal contact;
- rotate seating arrangements to assist in meeting people.